COMPUTER AIDED DESIGN
OF
TALL RC BUILDINGS

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OF
TALL RC BUILDINGS

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In Partial Fulfilment of the Requirements
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By
R. D. MANOHAR

to the

DEPARTMENT OF CIVIL ENGINEERING
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DECEMBER, 1988

To

My MOTHER

and
in memory of

My FATHER

5/12/88

C E R T I F I C A T E

This is to certify that the work presented in this thesis " COMPUTER AIDED DESIGN OF TALL RC BUILDINGS " submitted by Shri R D Manohar in partial fulfilment of the requirements for the degree of Master of Technology of the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried out by him under my supervision. The work embodied in this thesis has not been submitted elsewhere for a degree.

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PASALA DAYARATNAM
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Dec 1988

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On this day I remember my Alma mater Vidya Vardhaka Sangha High School, Bangalore

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A B S T R A C T

Most of the commercial, office, residential and institutional buildings that are built in the metropolitan cities of India today, fall in the range of 12 - 20 storeys Practising Engineers and Architects have to put in lots of effort for data preperation, if computer analysis of the building frame is opted for In the present work a computer software for the complete analysis and design of such tall RC buildings has been developed. This package has a professional application and can be used by an Engineer/Architect without getting involved in structural details, codal provisions or design manuals The detailing work for the designer has been obviated to a great extent, by providing complete reinforcement details

<u>This work has five distinct stages enumerated below</u> -

1 Generation of the geometry of the building frame with joint and member properties.

2 Generation of load vectors for all basic loads as per the relevant IS Code provisions

3 Analysis of the building frame and its components for all basic loads

4 Design of Beams and Columns

5. Design of a simple type of Foundation

Emphasis has been exercised to provide an economic and safe design. The input data has been very much simplified and kept to bare minimum. Effort has been made to optimise the computer time.

N O M E N C L A T U R E

A_C : Combined joint load vector in the direction of structure axes

A_E : Equivalent joint load vector in the direction of structure axes

A_{FC} : Combined joint load vector corresponding to free displacements (structure axes)

A_J : Joint load vector corresponding to external actions applied at joints (structure axes)

A_M : Final member end actions (member axes)

A_{ML} : Fixed end actions in members due to laods (member axes)

A_{st} : Area of tensile reinforcement

A_{sc} Area of compression reinforcement

A_{sv} : Total area of stirrup legs

A_{tc} : Area of reinforcement in the central band width in a rectangular footing

A_x : Area of cross section

b : Breadth of beam or column section

B : Shorter side of rectangular footing

C : Total compressive force in concrete at a section

C_x : X & Y direction cosines of member w.r.t structure axes

C_1 : Maximum compressive force in concrete at a section

C_2 : Compressive force carried by steel in compression

D : Overall depth of section

D_F : Free joint displacements (structure axes)

D_J Joint displacements for all joints (structure axes)

DL Dead load

d : Effective depth of section

d' Effective cover to tensile reinforcement

d_c : Effective cover to compression reinforcement

EL : Earthquake load

E_S : Modulus of ealsticity of steel

f_{ck} : Characteristic compressive strength of concrete

f_{vy} : Permissible tensile stress in shear reinforcement

f_{yd} : Design strength of steel

h_o Depth at the tapered edge in rectangular footings

I_z : Moment of inertia of section about z axis

j : Nuetral axis factor

k : Factor for depth of nuetral axis from extreme compression fibre, in column c/s

k_1 : Coefficient for area of stress block

k_2 : Factor for distance of c.g.of the compressive force from extreme compression fibre in column c/s

LL : Live load

LSD : Limit state design

L : Longer dimension of footing

M_c : Bending moment at critical section

M_u : Design moment acting at a cross section

$M_{u,lim}$: Limiting moment of resistance ofa section without compression reinforcement

M_r : Moment of resistance

M_{FAB} : Fixed end moment at end 'A' of beam AB

M_{FBA} : Fixed end moment at end 'B' of beam AB

P_u : Design axial load

p : Upward pressure intensity of soil

R : Rotation transformation matrix

R^T : Transpose of 'R'

SBC : Safe bearing capacity

S_{FF} : Overall joint stiffness matrix (structure axes)

S_M : Member stiffness matrix (member axes)

S_{MS} : Member stiffness matrix (structure axes)

S_v : Spacing of vertical stirrups

T : Total tensile force in tension steel

T_c : Design shear strength of concrete

T_v : Nominal shear stress

T_c^{max} : Maximum shear stress for concrete

V_u : Shear force due to design loads

V_{us} : Design shear force to be carried by stirrups

WL : Wind load

WSD ·	Working Stress Design
x_u	Depth of nuetral axis
x_u^{max}	Limiting value of x_u
x_m, y_m, z_m	The set of orthogonal axes for member axes
x, y z	The set of orthogonal axes for structure axes

Chapter 1 : INTRODUCTION

1.1 HISTORICAL REVIEW :

Digital computing began more than 2400 years ago when the chinese invented the abacus More than 2000 years elapsed before Pascal developed the adding machine. Leibnitz's multiplying-calculating machine was completed in 1694 In 1883, Babbage proposed his analytical engine similar to the electronic computers of today. ENIAC (Electronic Integrator and Calculator), the first digital electronic computer became oerational at the university of Pennsylvania in 1946. Three years later EDSAC (Electronic Delay Storage Automatic Calculator), the first stored program computer, became operational at the university of Cambridge. And in 1957, FORTRAN became operational for the IBM-704 after 3 years of development (Reference King Elwyn [12])

The exact date of birth of Civil engineering computer speciality is unknown, its practice is about 30 years . The beginning of the FEM (Finite Element Method) can be traced back to 1943. In that year the mathematician Courant [5] published a paper, using a method which we now recognise as the FEM. Synge [16] also a mathematician elaborated further on the method in 1952 and described it in full detail in a book in 1957. Synge made use of desktop calculators for his analysis, but he was fully aware of the power of electronic computers for this kind of computation.

Engineers however, did not pay much attention to these mathematical approaches, and the FEM in a more proper sense may be said to have started in 1954-56 by the pioneering works of Argyris [1] in London and Clough [4] and his group in Berkeley. Since then a nearly uncountable number of reports and articles and numerous text books on FEM have been published. Among the predominant names in the field, Zienkiewicz [22] and his team in Swansea should be mentioned

In the same way that the method of 'Moment Distribution' made possible the extensive use of continuous structures, the existence of large capacity high speed computers has now made it practicable to analyse and design highly indeterminate structures of new and unusual geometries subjected to complex time-dependent loadings The Stiffness method has received wide acceptance in the past two decades.

Where exactly does the popular Stiffness method fit into the tree of Structural analysis ? This is represented pictorially in Fig 1.1 Numerical methods have to be invariably adopted, for complex structures, as Analytical methods are imposed with limitations. Numerical methods can be further divided into 2 categories, viz;

(i) Numerical solutions of differential equations : In this type the equations of elasticity are solved for a particular structural configuration, either by finite difference technique or by direct numerical integration. In this approach the analysis is

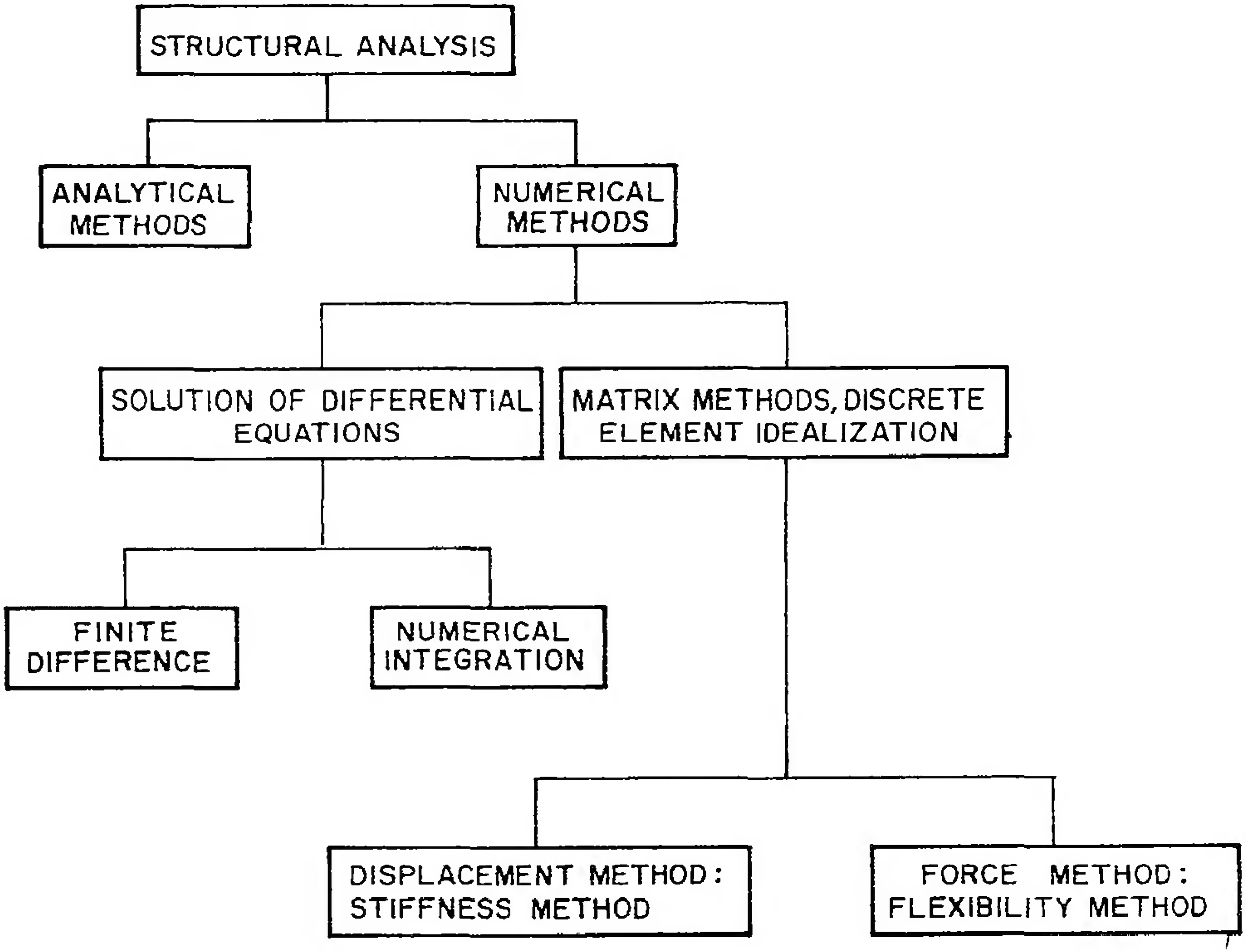


Fig.1.1 Tree of structural analysis

based on a mathematical approximation of differential equations. Practical limitations however, restrict the application of these methods to simple structures

(ii) Matrix methods based on discrete element idealization : In the matrix analysis complete structural theory is developed through all stages in the analysis

Later on, the need to develop suitable solution techniques was emphasised. During the mid 60's a number of solution techniques were developed for solution of linear equations. The 'Matrix Inversion method' was one of the earliest of the solution methods adopted. Selective inversion of stiffness matrices was later on recognised (James L. Tocher[20]) The 'Gauss Elemination' for symmetric, positive definite matrices coupled with 'back substitution' came to be the simplest and quickest way to solve systems of linear equations. Tezcan[19] provided some alarming results regarding the memory capacity for large structural problems For instance unless advantage is taken of symmetry and band-form of the coefficient matrix, the maxmimum number of equations that can be solved is approximately 40 with an IBM 1620, considering a rigid jointed space frame, it would mean a maximum of only 7 joints. However, it is possible to increase these capacities tremendously Capacity was found to increase from 40 to 840 with an IBM 1620. Tezcan suggested some

improvisations to be adopted, which are listed below :-

(i) Use of code numbers at almost every stage of analysis

(ii) Use of transformed member stiffness matrices in connection with the code number approach Thus obviating the need for both displacement transformation and standard transformation. As a result the main stiffness matrix is generated 25 times faster and there is considerable savings in data preparation and computer storage

In the meantime POLs (Problem Oriented Languages) were developed. STRESS (STRuctural Engineering Systems solver) was developed by Fenves et al <9> The wide spread succes of STRESS, indicated the need for such programming languages.

The next phase in the development of Structural engineering and Computers was Interactive analysis and design. Immediately after this came the fascinating subject 'Computer Graphics', which when coupled with interaction was termed as 'Interactive Computer Graphics'

The biggest disadvantage in using computer oriented stiffness analysis lies in preparation of input data. The preparation of data is a very tedious job, which often cause frustration to the user. To a large extent, they can be obviated if the data preperation is automated using 'Preprocessors'. Then the limelight shifted to Pre- and Post-processors which are rapidly becoming essential features for all general purpose FEM programs. In general terms Preprocessor means the progeam which precedes the main Analysis program and feeds the necessary input

for analysis. Postprocessor refers to the Design program which follows analysis A design and analysis software without a Preprocessor is not worth its value

1.2 TALL BUILDINGS :

What is a tall building ?

A suggested definition is, it is a "building in which 'tallness' strongly influences planning, design and use" or in simpler terms it is a "building whose height creates different conditions in the design, construction, and use from those that exist in 'common' buildings of a certain region and period".

Depending on their utility, tall buildings can be classified into :-

i) **Commercial** : office, store & shops, bank, public utility

ii) **Residential** . apartment (rental and condomonium), hotel, dormitory, hostel.

iii) **Industrial** . warehouse, manufacture, material processing

iv) **Institutional** · school,hospital (health care facility) laboratory, library, museum, court of law, religious edifice.

v) **Public assembly** · theatre,hall and auditorium(meeting rooms), restaurant, observation.

vi) **Special purpose** : transport interface (air, rail, bus, ship), garage (parking deck), mousoleum.

vii) **Multiple use** · megastructures that are various combinations of the above.

<u>Structural systems in tall buildings</u> :

The most frequently used tall building structural systems for concrete structural frames based on their tallness criteria are shown in fig 1 2 (Khan <11>) The present work is limited to tall RCC building frames upto around 20 storeys Most of the commercial and office buildings built in urban India invariably fall into this category

<u>Foundation systems in tall buildings</u> :

Tall buildings because of their height, stiffness, and usually urban location, encounter foundation problems requiring special consideration Column loads tend to be very heavy. Adjoining areas are usually occupied, streets are busy underlain by a maze of sewers, water mains and electrical conduits. Essentially the type of foundations depends on many factors, some important factors are listed as under .-

i) Characteristics of foundation soil (type of soil, bearing capacity, water table, friction angle, etc.)

ii) Type of structure

iii) Type of loads

iv) Permissible differential settlement

v) Economy

Foundations systems for RCC multistoreyed buildings may be broadly grouped under the following headings :-

i) Isolated footings

ii) Combined footings

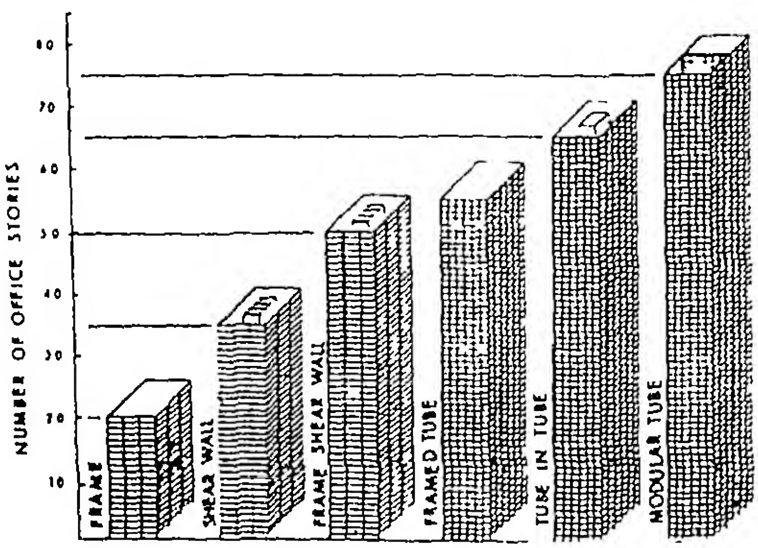


Fig. 1 2 Concrete structural systems (Khan et al[11])

iii) Raft foundations

iv) Deep foundations

Where stable and hard soils are encountered at a reasonable depth , Isolated footings may be found to be suitable subject to structural needs However, in weak soils and heavy column loads raft foundation becomes an obvious choice. In regions where weak, compressible or soft soils are encountered at shallow depths, then the foundations are to be carried to deeper depths to result in higher stregth and stability Lateral loads due to wind or earthquake increase with the height of the structure and are to be ultimately carried to and resisted by the soils of the foundation, and this can be achieved by Deep foundations Decisions and design of a suitable foundation system should be based on a sound understanding of the foundation condition Excessively heavy loadings, large or erra tic column spacings, or variations in weight of the structure in plan may significantly increase costs Adequate time must be allowed to study & bring about a coordination between foundation studies & planning and structural engineering, if economy is to achieved.

1.3 REVIEW OF WORK DONE AT IIT KANPUR :

Review of the past works done in the relevant CAD field at IIT Kanpur revealed some interesting programs. A few of these are summarised below to indicate the growth of the state of art in the relevant CAD field

A program "HIRISE" developed by Dr. P.Dayaratnam[7] is a compact package for analysis and design of roof trusses, towers and multistorey buildings The author was associated with Dr. P Dayaratnam in using this versatile package in various projects, which revealed many practical aspects involved in computer analysis and design of RCC building frames

An M.Tech thesis "Computer Aided Design of Industrial Building", by Sharma A.K[17], is a package which does the analysis and design of various components of an industrial building It has a preprocessor for generating geometry and loads. The preprocessor is a highly flexible and has graphic support

V V.S Sitaraman[18] in his M Tech thesis "Computer Aided Design of small Industrial buildings", has a preprocessor, analysis and design modules It is usable for a set of standard roof trusses

Literature survey revealed many more works done at IIT Kanpur, only a few relevant examples were cited above.

1.4 INTRODUCTION TO PRESENT WORK:

In present work named "Computer Aided Design of Tall R Buildings" the objective was to develop a software package for analysis and design of plane RCC building frames The package has been developed with emphasis to practical applicability. The present software can be used effortlessly by an architect/engineer without getting involved in structural details. During the

developmental stages of this software immense care has been exercised not only to conduct an efficient analysis and design of the structure but also minimize input data for such programs

The program constitutes of three basic modules , which enables the user to have a stagewise check on input and also minimises the memory requirement The entire software has been developed making use of the facilities available at the Computer Centre, IIT Kanpur. The entire package is compatible to be run on a personal computer. The three basic modules are :-

i) Preprocessors

ii) Analysis module

ii) Design module

The Preprocessor module is further divided into 2 parts viz;

(i) Generation of Configuration

(ii) Generation of Loads and Forces

The first stage Preprocessor processes the basic input information and generates the geometry of the structure, the joint and member properties One of the important attributes of this program is that the skeleton drawing of the building frame can be displayed on the screen without any graphic facility This proprocessor is capable of generating almost all general configurations & some complex configurations which may be encountered in tall buildings

The second stage Preprocessor generates loads and forces required

for analysis for the 3 basic loads (Dead Loads, Live Loads, Earthquake/Wind Loads) Dead Loads and Live Loads are generated as per the provisions of the code IS 875-1964 An option for reduction of Live Loads on columns and foundations as per IS 875-1964 is also provided Response spectrum method is used for Modal analysis of the structure to simulate the dynamic behaviour of the structure during an earthquake The program has the adaptability to take care of some of the common features of tall buildings like lifts, water-tanks, canopy projections & other such features which introduce extra loads and/or moments on the frame This preprocessor can also handle beams subjected to point loads at midspan In case of beams subjected to unusual type of loading generated data can be alterred during analysis in an interactive mode.

The Analysis module is executed independently with input provided by the preprocessors The program uses the well known Stiffness method for analysis During analysis all the data needed for Design module is prepared and available through interface files.

The Design module consists of two parts viz;

(i) Design of members (Beams and Columns)

(ii) Design of a type of foundation

Only two inputs are to be typed for the execution of the entire package. Extra information if needed will be asked by the program in a user friendly conversational mode. This is optional and is used only under special circumstances. Error

messages are printed out on the screen and execution terminated immediately, if any anamoly is found in the input data Error messages clearly point out as to the source of error another important attribute of this package is the Preprocessor and Analysis modules can be used in any of the three standard units SI, MKS and FPS The Design module is invariably developed in SI units, the user is obviated from manipulation of any input data as the program automatically does this The user should specify the working system of units

The programmed is named as ADOMS (Analysis & Design Of Multistorrey Structures) A general flow chart of the program is represented pictorially in fig 1 3

The salient features of the program are listed below:

Name of the program	·	A D O M S
Type of Structures	·	Plane RCC Building Frame
Method of Analysis		Stiffness method
Method of Design		Limit State Design
Components designed		Beams, Columns & Footings
Codes of practice used		IS 875 - 1964 IS 1893 - 1984
Number of Modules	:	THREE 1 Preprocessor 2. Analysis 3 Design
Programming language		Standard FORTRAN
Operational on	.	1> Dec 1090 (IIT Kanpur) 2> Personal computers

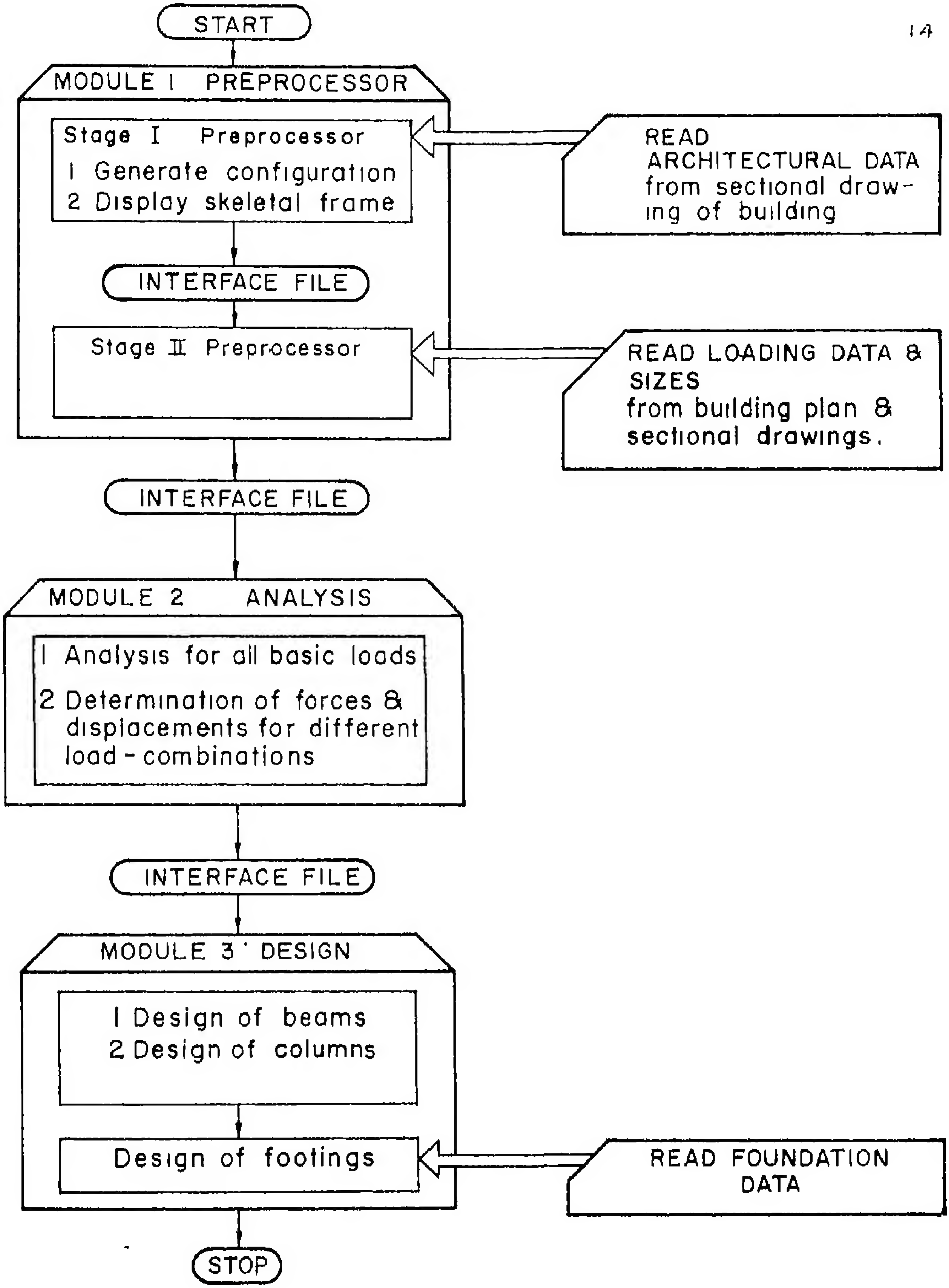


Fig 1.3 General flow chart of the complete software

1.5 Organisation of Thesis :

The overall thesis is presented in four chapters The current chapter " INTRODUCTION " presents a concise historical and literature reivew and introduces salient features of the present work

The second chapter " PREPROCESSOR " deals with features and characteristics of preprocessors and explains in detail about the preprocessor developed for the present work It also illustrates input preperation and output understandign with an example problem

Chapter three " ANALYSIS & DESIGN " is divided into two basic parts The first part deals with analysis of the structure subjected to various kinds of loadings General understanding of the output files is explained with an example problem. The second part covers the design of beams, columns and footings. Design output files are also presented for an example problem with appropriate explanations

Chapter four is " DISCUSSIONS AND CONCLUSIONS " , which discusses about the practical implications of the two methods suggested for Seismic analysis in the IS 1893 - 1984 Finally in this last chapter the conclusion for the present work is put forth.

CHAPTER 2 _ PREPROCESSOR

2.1 **General** : Preprocessor is a computer program preceding the main program, and provides the requisite input data needed in the main program. Preprocessors are labour saving devices and are employed in automatic generation of all the information necessary for the analysis of the structure:- the geometry, the joint and member properties, the boundary conditions and the loadings on the members They provide the flexibility to check and alter data prior to the analysis

2.2 **Review of some Preprocessors** :

Literature survey revealed many efficient preprocessors, some of them have discussed briefly to indicate the state of the art

Masser J [14] in his paper " Interactive data preprocessing for Michigan SAP ", prepares input data for the MSAP (Michigan SAP). It is an interactive preprocessor which accepts input in free format Carlos I Pesquira et al [15] in their paper " interactive graphical preprocessing of three dimensional framed structures " have given general concepts and requirements of interactive graphical preprocessor for 3-D structures Iwaki & Maeda [10] developed a general purpose FEM program MISA, which is designed to have a high performance pre & post processor.

Sharma A.K. [17] in his M Tech thesis " Computer Aided Design of Industrial structures ", presents a very efficient interactive preprocessor which generates geometry of the structure and loading details. It has the flexibility of adding and deleting any nodes

and or members It has a Graphic support and draws the frame geometry on the video console.

2.3 Features of the present Preprocessor :

Although many preprocessors have been developed which can handle a wide variety of 2-D/3-D structures, but a preprocessor specific to a certain problem is not common The present preprocessor has been developed to the specific problem of multistoreyed building frames and has the advantage of feeding the input data effortlessly. Interactive mode of input feeding is invariably avoided. Design decisions which need careful study are to be taken in a very short time in front of the terminal in an interactive mode, and this is not adoptable practically

The preprocessor is executed in two stages viz,

(i) Generation of Frame configuration

(ii) Generation of Loads and Forces

(A) GENERATION OF FRAME CONFIGURATION :

2.4 Introduction : In this first stage preprocessor named 'CONFIG', joint coordinates and member connectivity are generated. The input data to this preprocessor can be easily given with the help of a sectional drawing of a given building. The skeleton drawing of the plane frame is sketched which can be printed out using a line printer or a dot-matrix printer, without any graphic support. The joints,beams & columns are numbered at appropriate locations in the frame figure.

2 5 <u>The significant aspects of this preprocessor are listed below</u> :

Name of the program	C O N F I G
Program size	350 lines (total)
Subroutines	ONE
	1 FIGURE
Input data	File name = DAT1 INP
	(Format free)
Output data	File name = GENE DAT
Interface data	1 File name = LOAD1 TEM
	2 File name = ANAL1.TEM

Generally occurring anamolies during typing of input data are recognized and the program is terminated immediately with an error message indicating the source of error

The coordinate system used in the entire program is shown in fig 2 6 All joints are numbered from top to bottom. In case of members , beams are numbered first and then columns follow, the sequencing is again from top to bottom

Figures of the Flow charts have been presented to indicate the technique adopted for programming

2.6 <u>Input/output illustration</u> .

Input data is typed in a file named DAT1 INP, in batch mode in a format free environment (title cards are exceptional). The details of input data is shown in Table 2 1 , with appropriate data card numbers The table is self explanatory, but some special features to be noted are .-

In case of a frame with same number of bays in all the storeys,

bay widths are to be fed only once that is for only bottom storey! so card numbers 6 to NS+4 are not to be fed. When the number of bays are found to be equal in all storeys, the program generates the bay widths for the remaining storeys treating the bay widths to be same in all the storeys Further more if 'n' number of storeys have equal number of bays, then the bay widths are to be fed only once for those set of 'n' storeys Hence bay widths are to be fed only for those storeys which have unequal number of bays.

In case the number of missing beams is zero, card number NS+6 is not to be fed

The values for JOK(1),JOK(2),. . JOK(7) are to be fed as an integer 999, which serves as a check for anamolies in input data that is being fed.

Given the Building plan and sectional drawings, How to prepare input data ? This question is answered with a reference problem shown in fig 2 7 The data cards for this example problem are given in Table 2 2

Output files generated by the program are presented in chapter 4

Table 2.1 DETAILS OF DATA CARDS . (DAT1.INP)

Card Number	I N P U T D A T A
1	TITLE CARD (column nos 1-60)
2	Row Number (column nos 1-5)
3	Number of storeys - NS
4	Height of storeys starting from base, JOK(1)
	Fore spacing of frames at each floor/roof level w r t present frame, JOK(2)
	Rear spacing of frames at each floor/roof level w r t present frame, JOK(3)
	Number of Offset bays in each storey w r t extreme left end, starting at base, JOK(4)
	Number of Bays in each storey starting from base, JOK(5)
5	Bay widths in bottom/first storey, JOK(6)
6	Bay widths in second storey, JOK(6)
.	. , ..
	. . . ., ...
NS + 4	Bay widths in top storey, JOK(6)
NS + 5	Number of Missing Beams
NS + 6	Storey number and Bay number of Missing Beams , JOK(7)

TABLE 2 2 EXAMPLE PROBLEM DAT1.INP

Card Number	INPUT DATA
1	EXAMPLE PROBLEM FOR ILLUSTRATION, IIT Kanpur, 1988
2	ROW B
3	6
4	4 5, 3 2, 3 2, 3 2, 3 2, 3 0, 999
	4 0, 4 0, 4 0, 4 0, 4 0, 4 0, 999
	3 5, 3 5, 3 5, 3 5, 3 5, 3 5, 999
	0, 0, 1, 1, 1, 2, 999
	5, 5, 3, 3, 3, 2, 999
5	4 0, 4 5, 4 2, 4 5, 4 0, 999
6	4 5, 4 2, 4 5, 999
7	4 2, 4 5, 999
8	2
9	1 2, 1 4, 999

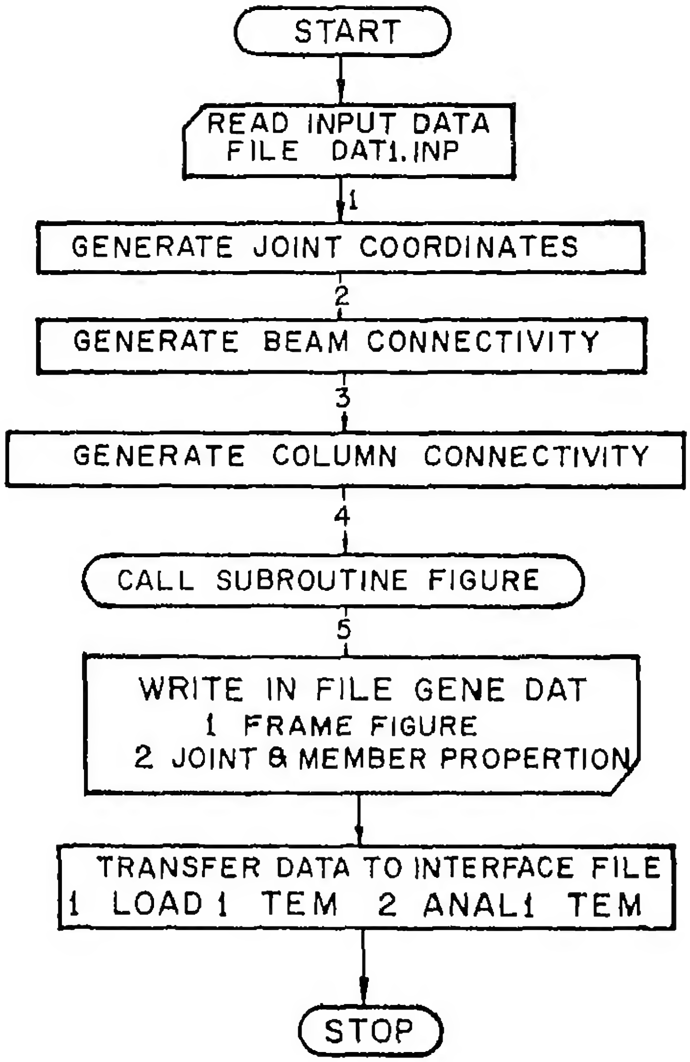


Fig. 2.1 General flow chart of preprocessor 'CONFIG'

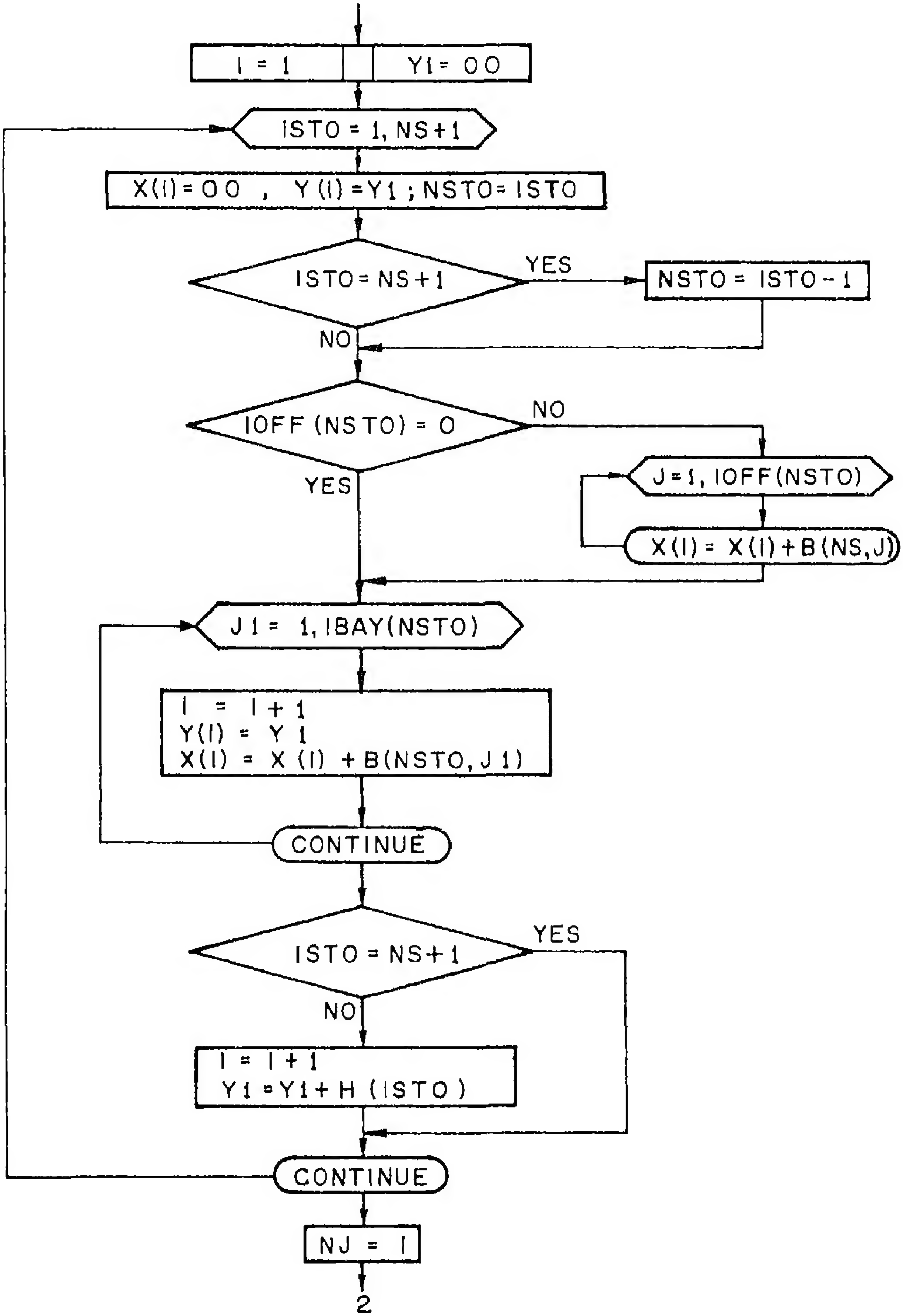


Fig. 2.2 Flow chart of generation of joint coordinates

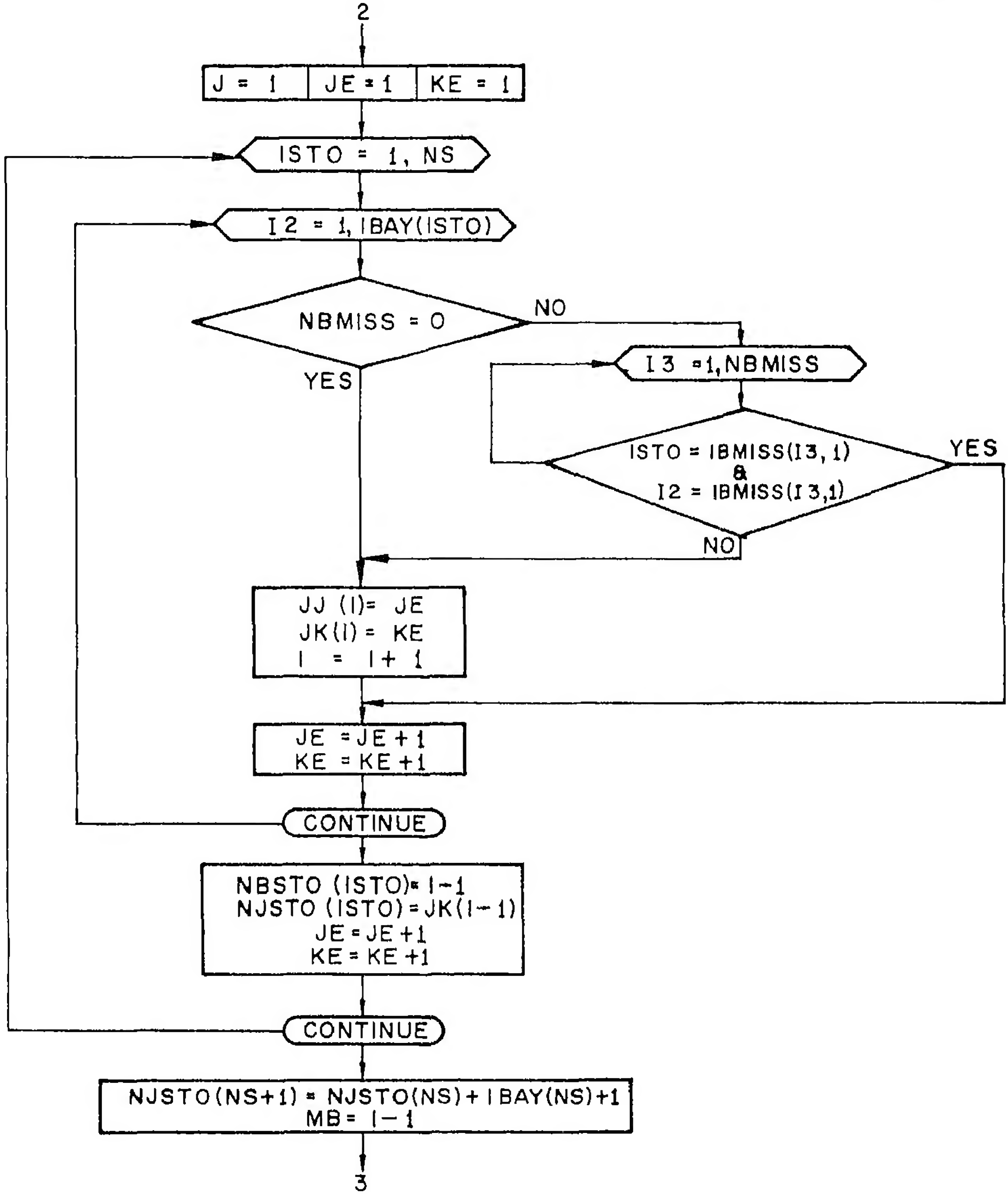


Fig 2 3 Flow chart for generating beam connectivity .

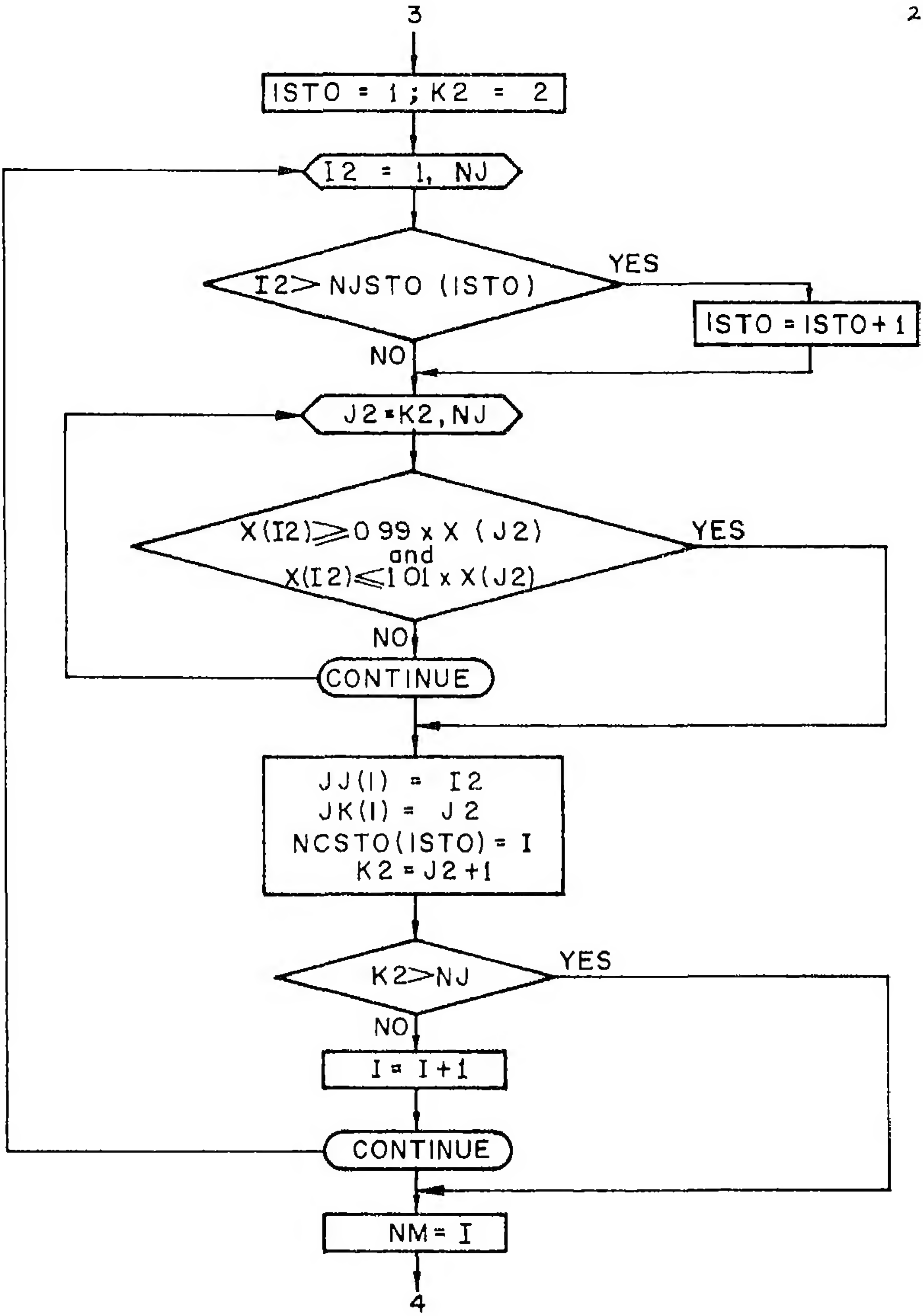


Fig.2.4 Flow chart for generating column connectivity

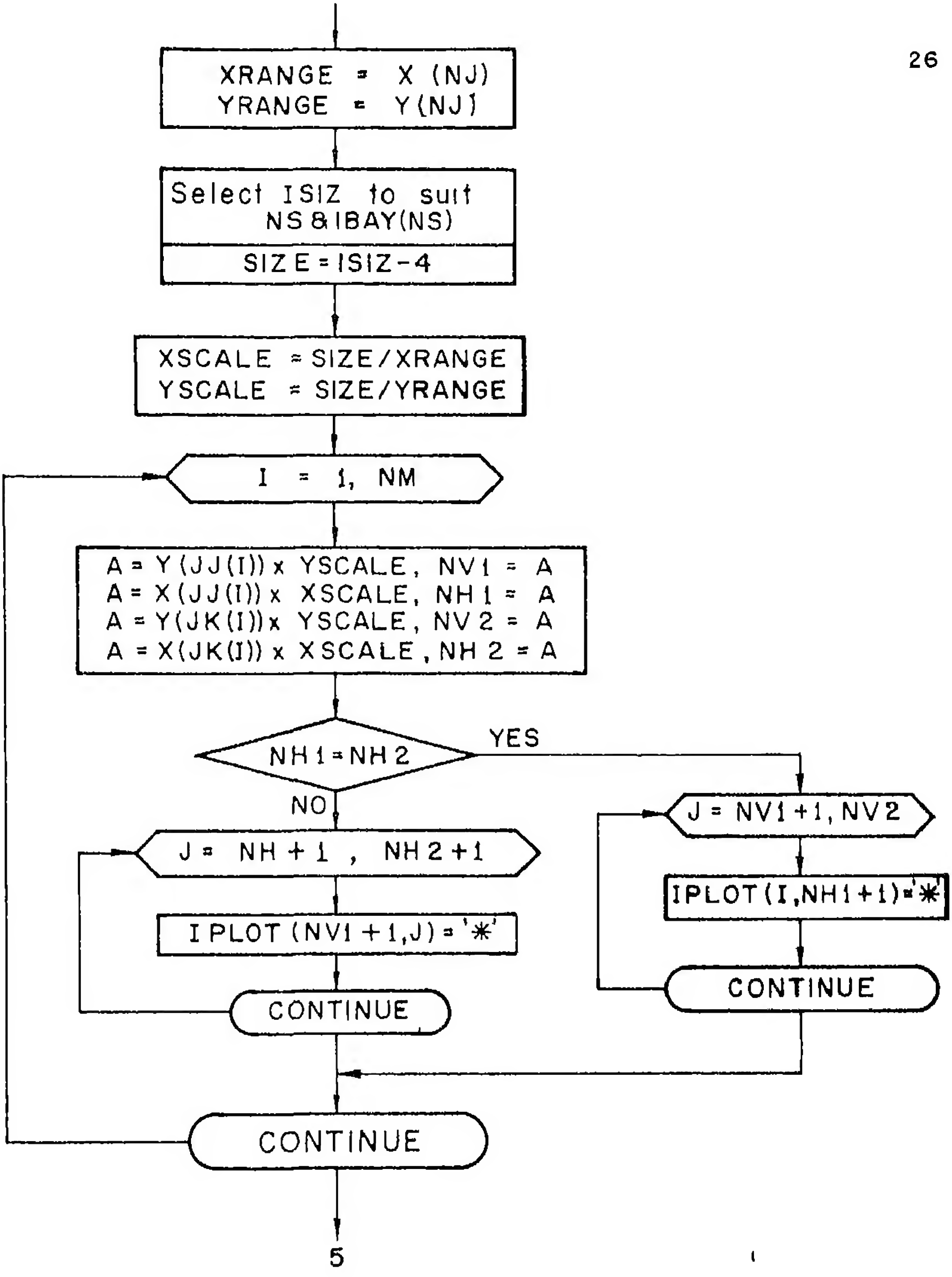
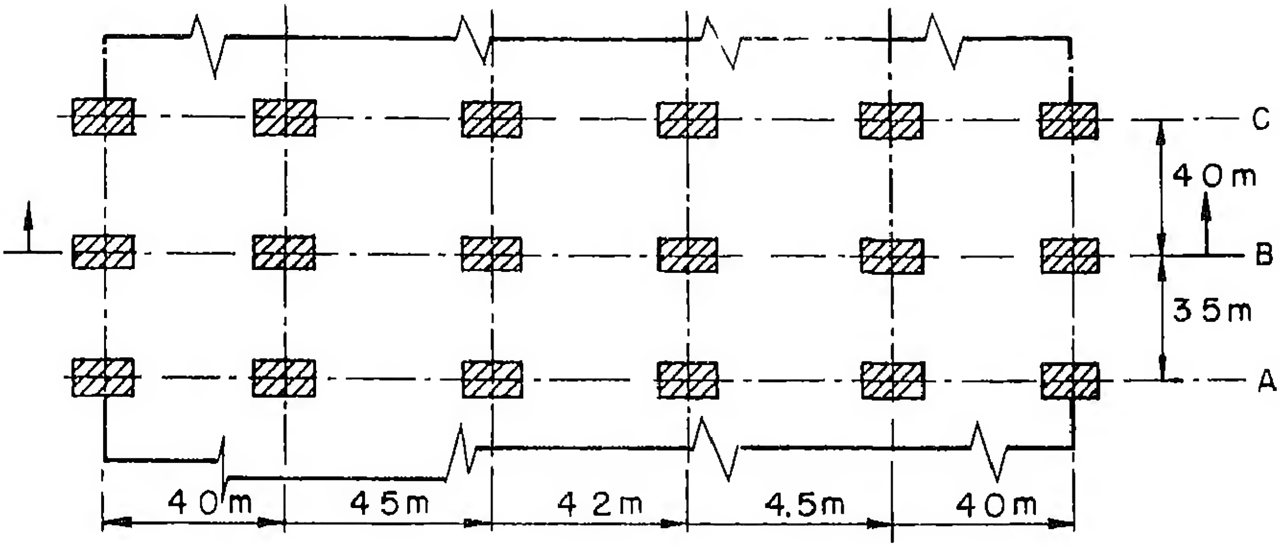
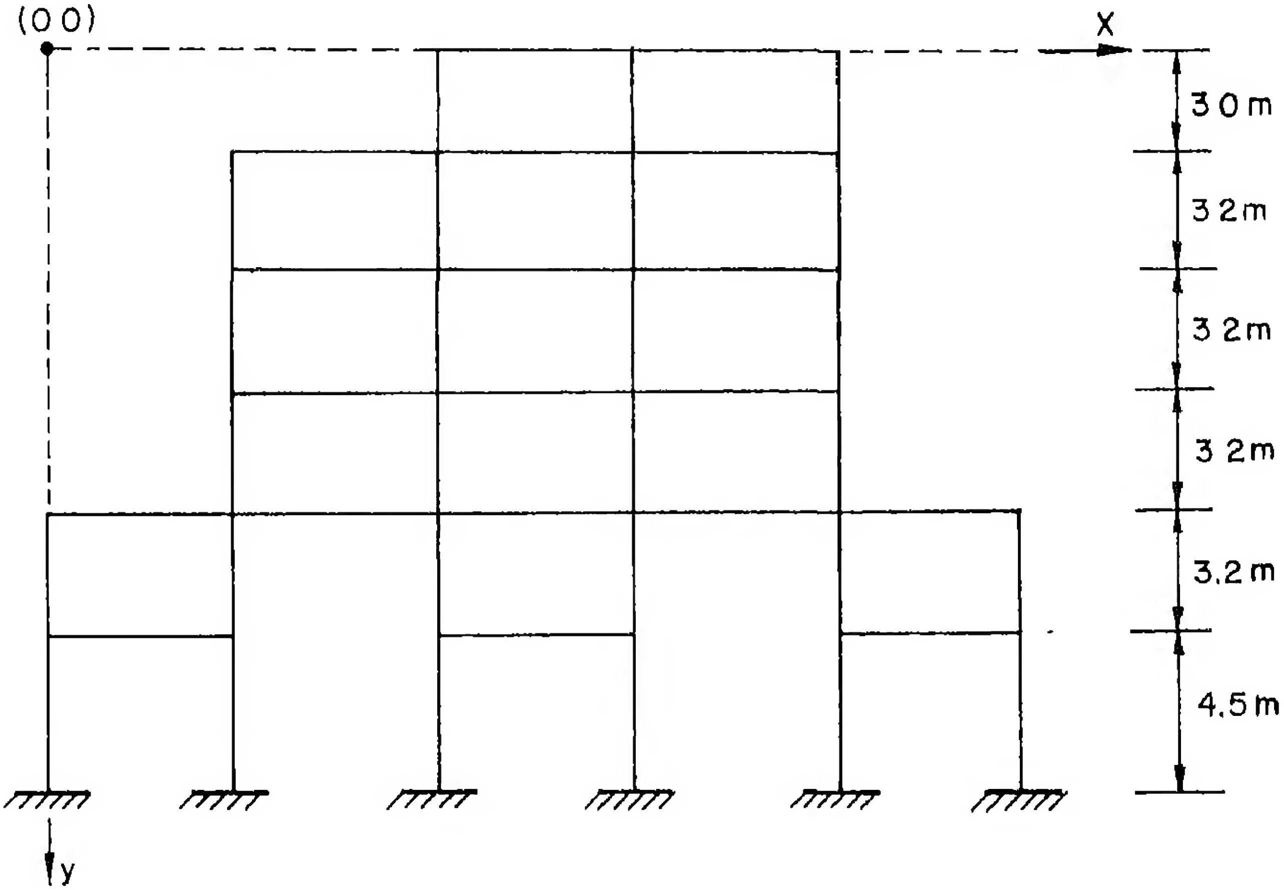


Fig.2.5 Flow chart for generating frame - figure (SUBROUTINE 'FIGURE)



(a) Ground floor Plan



(b) Skeleton section of frame B

Fig 2.6 Example problem : Architectural details

(B) GENERATION OF LOADS AND FORCES :

2 7 Introduction . In this second stage preprocessor named "LOADS", the loads and forces on the beams and the joints for three basic loads are generated This is a very powerful preprocessor and forms the basis for analysis and design The input data to this preprocessor can be given with the aid of the various floor/roof plan of the building under consideration

This preprocessor "LOADS" constitutes of 3 parts In the first part of the preprocessor beam loads, mid-span bending moments, fixed end actions are all generated The various loads taken into account are dead weight of beams, wall loads (if any), portion of slab dead load and live loads The program can take care of beams subjected to point loads at midspan.

2.8 Concrete characteristic strength · Beams are assigned characteristic strengths corresponding to 1.2·4 concrete mix, whereas columns are assigned characteristic strength depending upon the number of storeys. The different types of mixes used in for columns are 1 2·4, 1 1 5 3 & 1 1 2 This generated data may be alterred during analysis stage if desired

In the second part of the preprocessor, the loads transferred to joints from cross beams are generated. The various loads taken into account are dead weight of cross beam, wall load on cross beam (if any), portion of slab dead and live loads. Extra joint loads (if any) due to lifts, cantilever projections, etc is to be fed as input and added to existing values of joint loads This preprocessor serves the input data for analysis seperately for dead and live loads.

2.9 **Load distribution** : The pattern of load distribution depends upon the arrangement of beams & centre to centre spacing of columns The two of the general types of load distribution systems are shown in fig 2 7 (a) & (b) and fig 2.8 (a) & (b) The relevant clauses of IS 456 - 1978 have been incorporated The figures are self explanatory Depending upon the load distribution pattern the loadings on beams can be of 4 types, viz,

(1) Uniformly distributed loading pattern
(2) Trapezoidal loading pattern
(3) Triangular loading pattern
(4) Triangular + Point loading pattern

The different loading types on beams and the corresponding bending moment diagrams are indicated in fig 2 9 (a,b,c & d).

(1) Uniformly distributed loading pattern fig. 2 9 (a)

Free max bending moment $M_c = w\,L^2/8$

Reaction $R = w\,L/2$

Fixed end moments · $M_{FBA} = -M_{FAB} = w\,L^2/12$

(2) Trapezoidal loading pattern fig. 2.9 (b)

$M_c = w\,L(L-a)/4 - w\,a(L/4-a/3) - w\,(L/2-a)^2/2$

$R = w\,(L-a)/2$

$M_{FBA} = -M_{FAB} = w\,[L^3 - a^2(2L-a)]/12L$

(3) Triangular loading pattern . fig 2 9 (c)

$M_c = w\,L^2/12$

$R = w\,L/4$

$M_{FBA} = -M_{FAB} = 5\,w\,L^2/96$

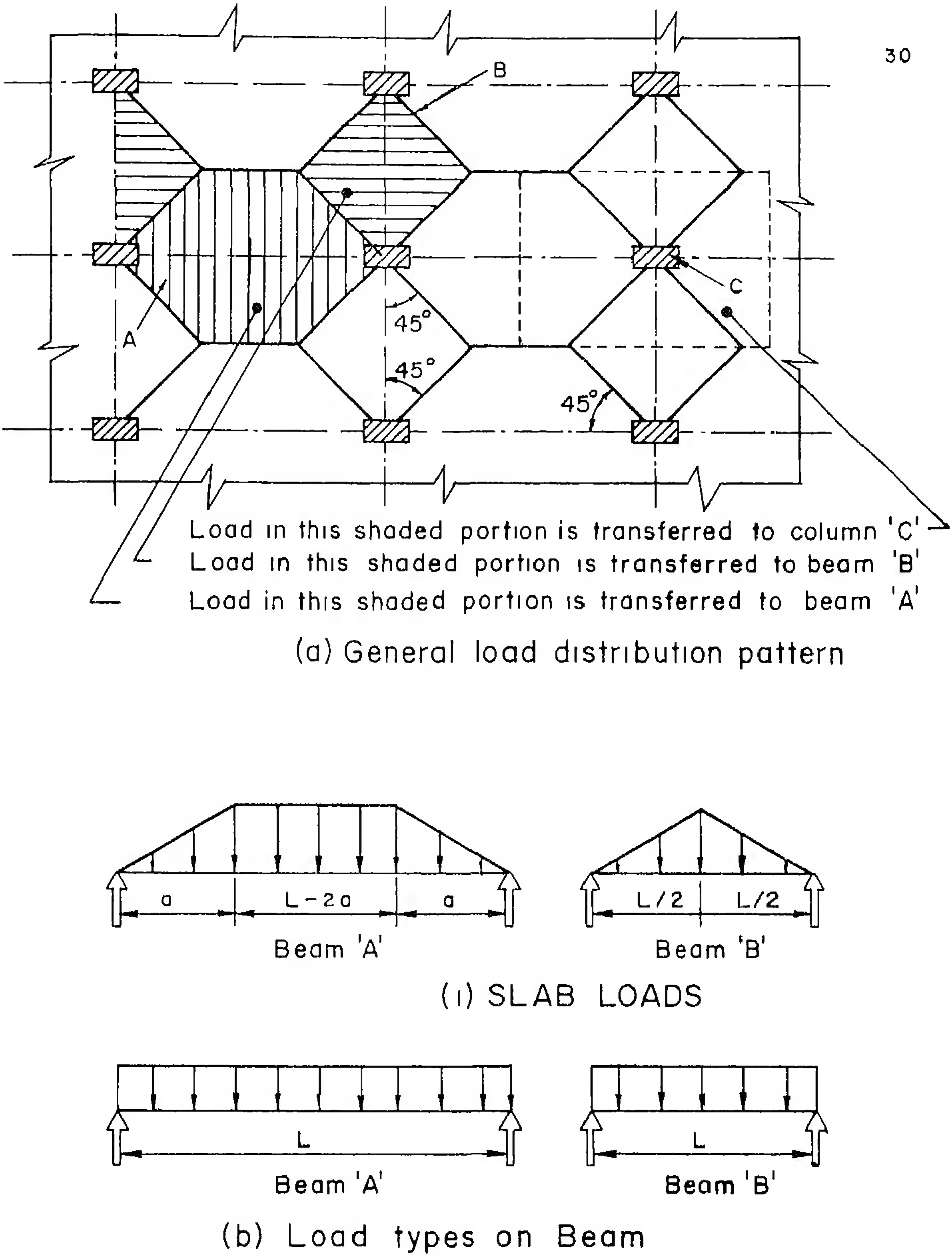
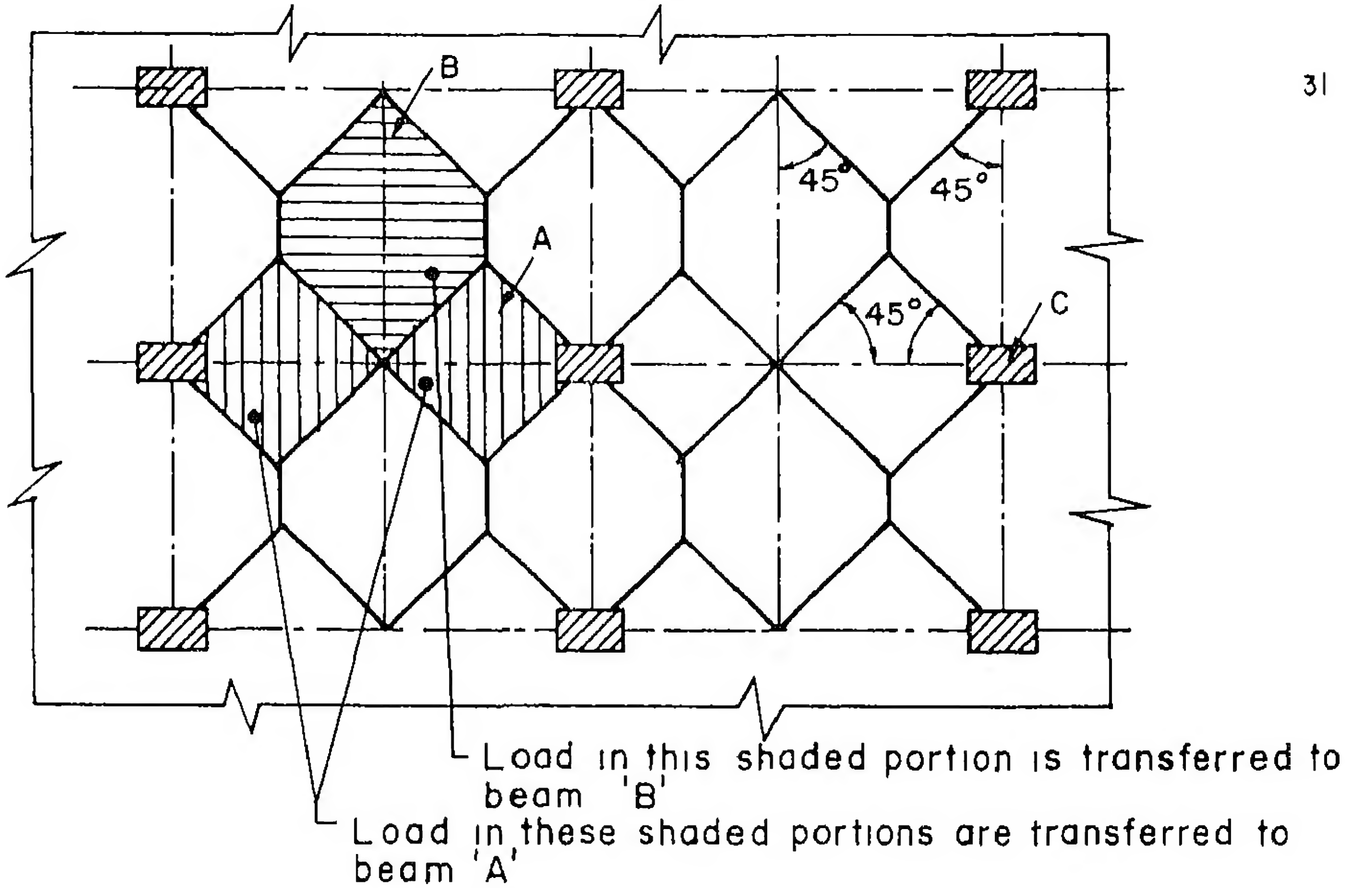
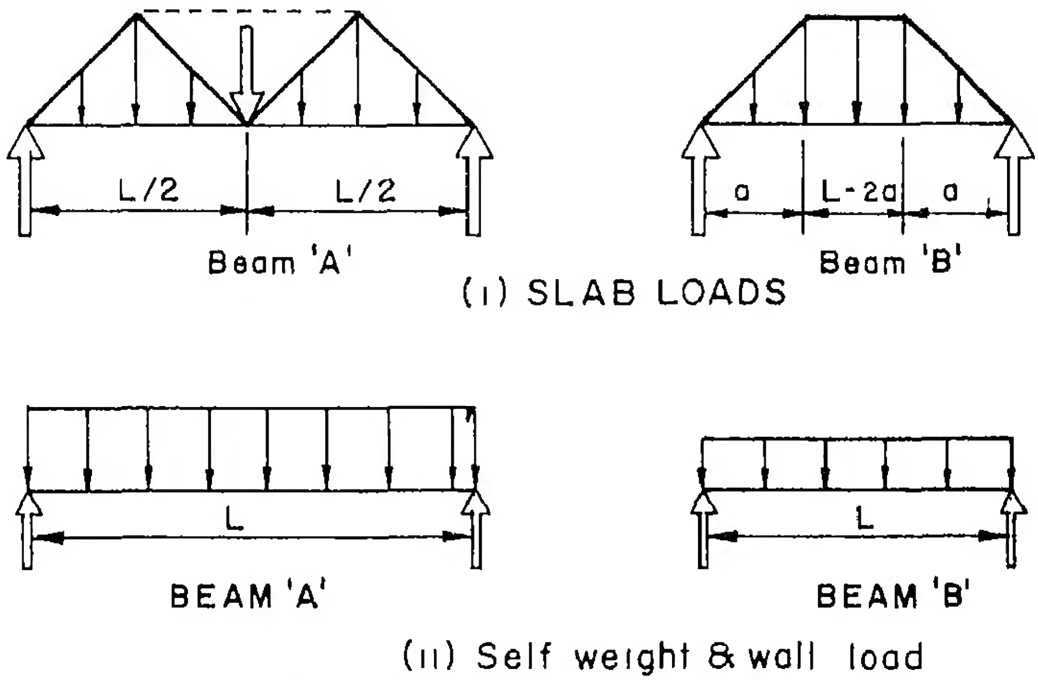


Fig 2.7 LOAD DISTRIBUTION SYSTEM TYPE - I

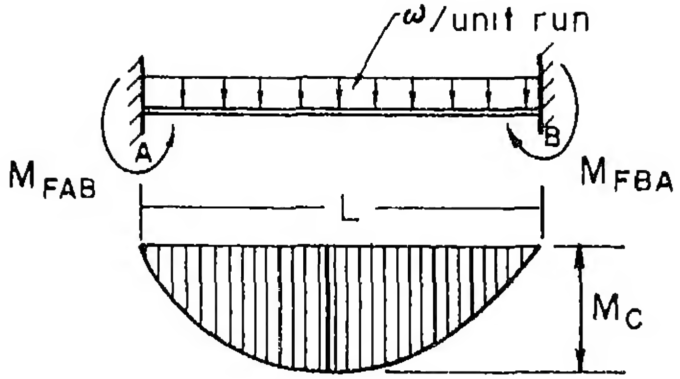


(a) General load distribution pattern:

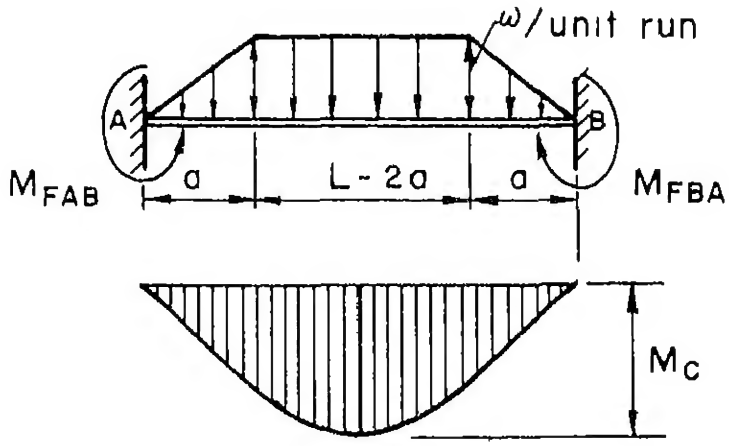


(b) Load types on beams.

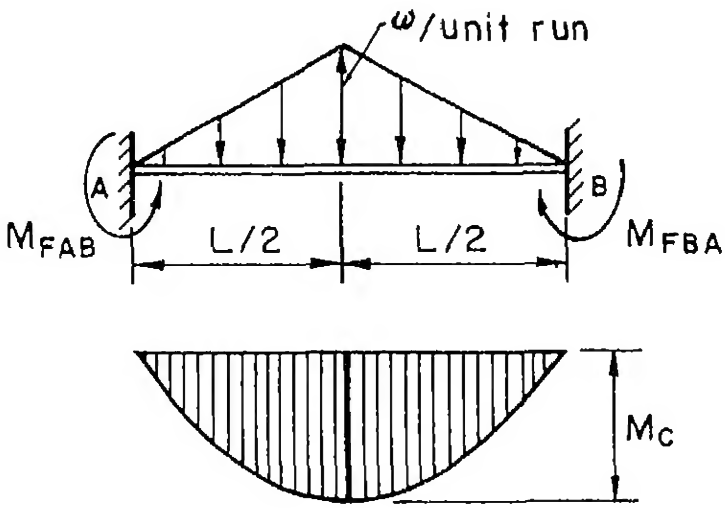
Fig 2.8 Load distribution system Type II



(a) Uniformly distributed loading

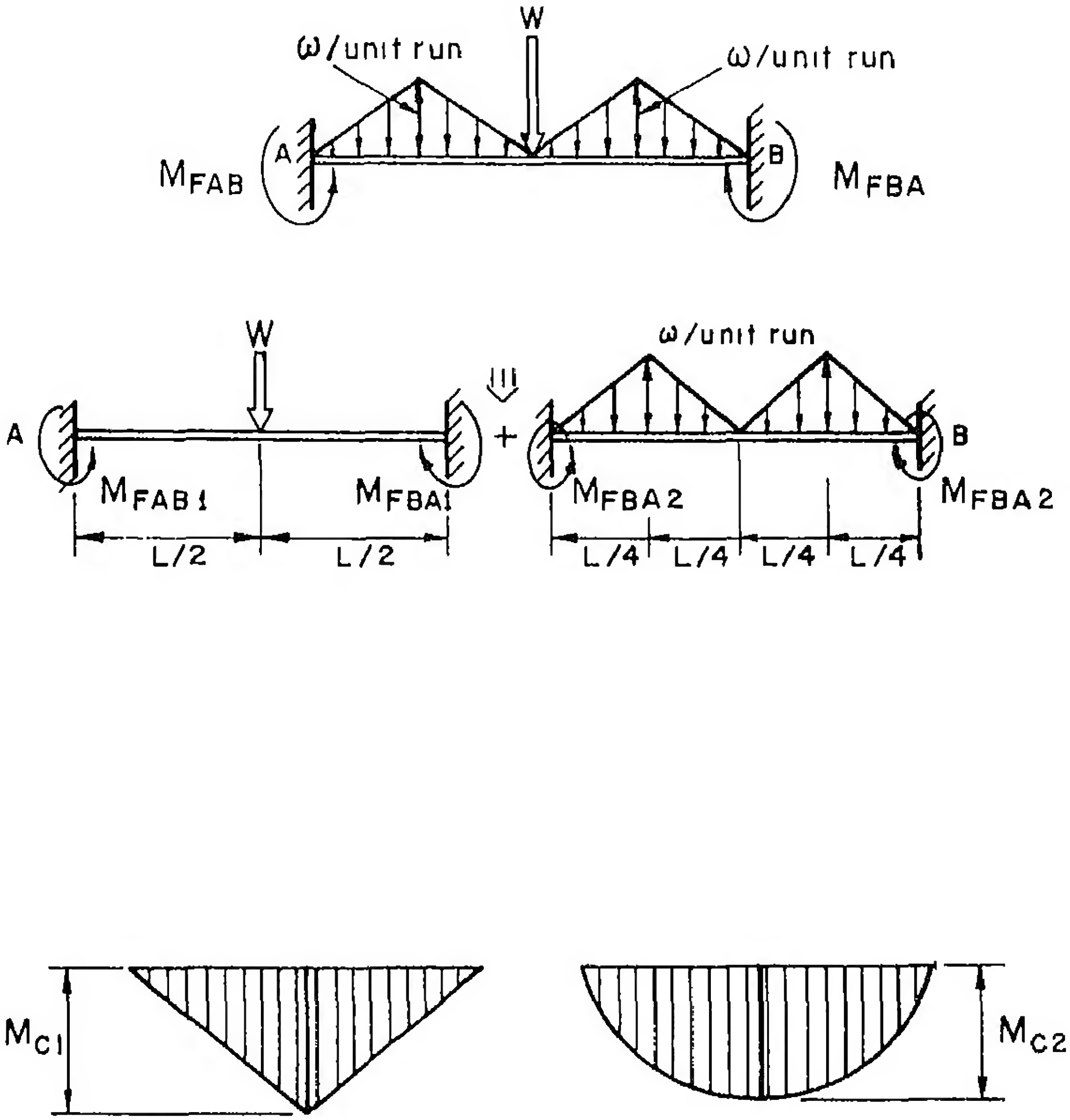


(b) Trapezoidal loading pattern



(c) Triangular loading pattern

Fig 2.9



(d) Double triangle & Single point loading pattern

Fig. 2.9 Beam loading types & free bending moment diagram

(4) Triangular + Point loading pattern fig 2 9(d)

$$M_C = w L^2/16 + W L/4$$

$$R = w L/8 + W L/2$$

$$M_{FBA} = -M_{FAB} = 17 w L^2/384 + W L/8$$

2.10 <u>Seismic</u> <u>analysis</u> . The third part of this preprocessor conducts the Seismic analysis of the building frame using Modal analysis technique (reference IS 1893 - 1984). During Modal analysis the eigen values, eigen vectors, time period, modal participation factors and the lateral shear forces are determined Three modes have been superimposed to arrive at the absolute maximum values of lateral shear The eigen solution is sought by a powerful but simple method known as the "POWER METHOD" The advantage in using this method is that the execution time is less as the solution is found only for a specified number of modes & at the same time the program size is comparitively small. More details about modal analysis is given in art 2.12 .

In zones subjected to high wind pressures, seismic analysis is dropped and lateral wind loads at each roof/floor level are to be fed as input.

2 11 The significant aspects of this preprocessor are :-

Name of program	L O A D S
Program size	750 lines (total)
Subroutines :	TEN

1 SUDL
2. SDOT
3. CSLOAD
4. MLOAD
5. MODAL
6. POWER
7. MATMUL
8. MATVEC
9. SCAVEC
10. VECLEN

Input data	File name : DAT2 INP (Format free)
Output data	File name SESMIC DAT
Interface data	1 ANALD TEM (DL) 2 ANALL TEM (LL & EL/WL)

Figures of flow charts are presented at the end of this chapter which provides an indepth view of the entire program

SUBROUTINES :

(i) SUDL : This subroutine calculates the fixed end actions in beams, due to slab dead & live loads and returns back to the main program Fig 2.14 provides the flow chart adopted for this subroutine

(ii) SDOT : This is similar to subroutine SUDL, with the only exception that this subroutine handles beams subjected to point loads at midspan

(iii) CSLOAD : This subroutine also functions on the same lines as the subroutines SUDL and SDOT The primary objective of this subroutine is to calculate the loads that are to be transferred to the joints due to slab dead and live loads

(iv) MLOAD : The total roof/floor wieghts, the overall stiffness of storeys are computed in this subroutine. Fig 2 15 shows the flow chart for the MLOAD subroutine

(v) MODAL : This subroutine performs the modal analysis of the building idealized as having a limped mass and stiffness in various storeys The dynamic response of multistoreyed building is conducted by this subroutine The technique of programming adopted is indicated by a flow chart in fig. 2.16

The descriptions of subroutines POWER, MATMUL, MATVEC, SCAVEC,

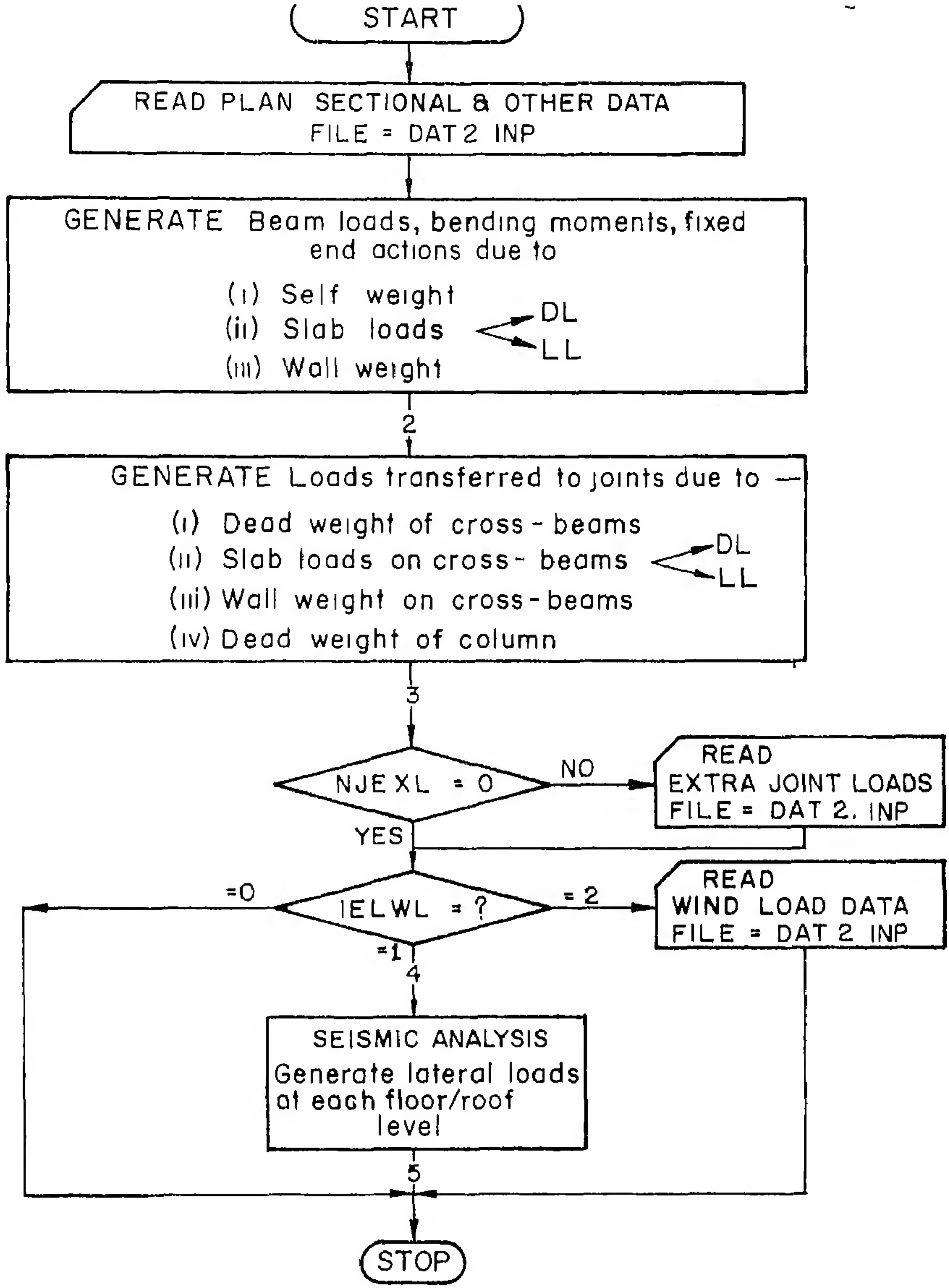


Fig. 2.10 General flow chart of LOADS preprocessor

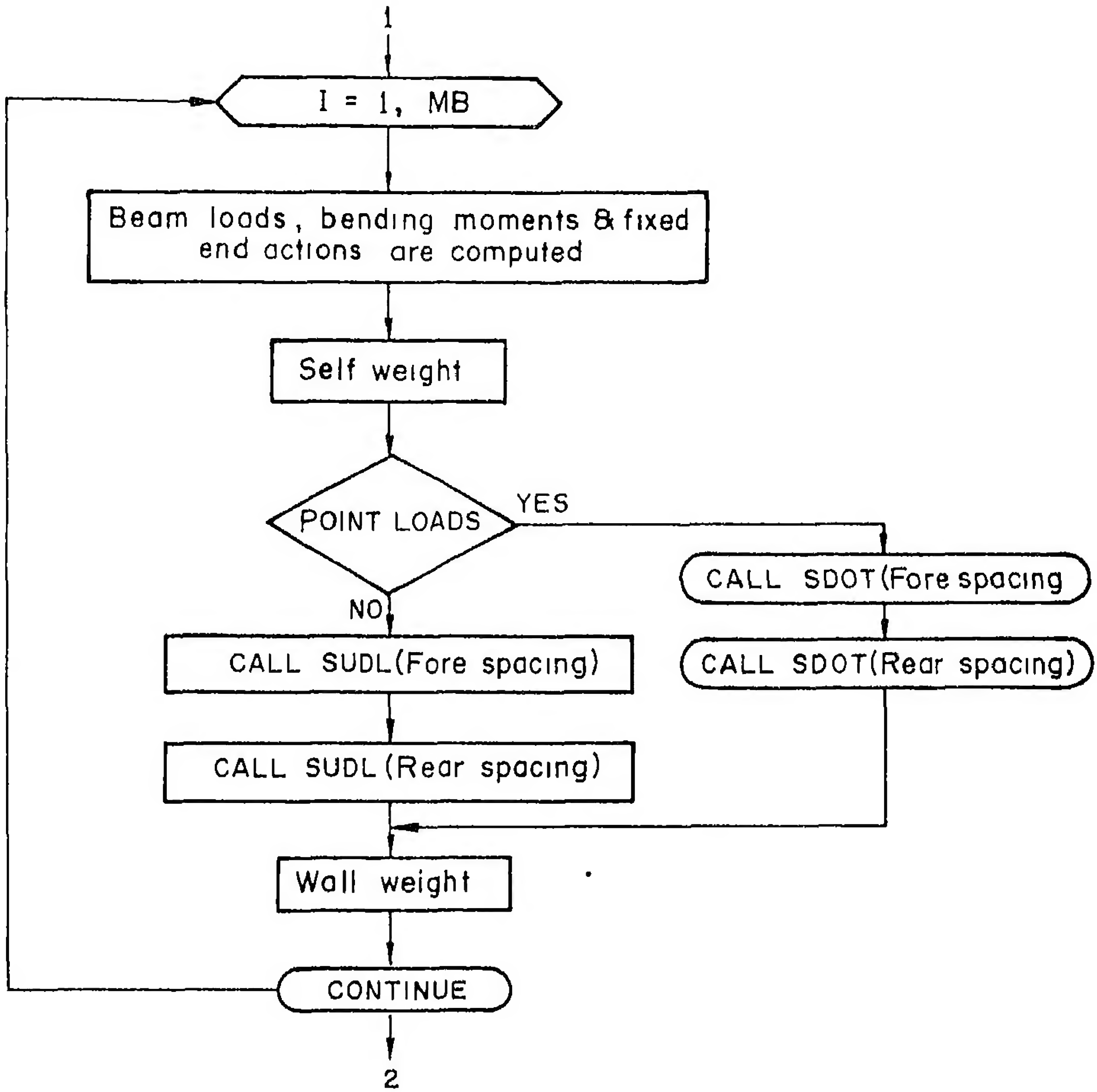


Fig 2.11 Flow chart for generation of member forces.

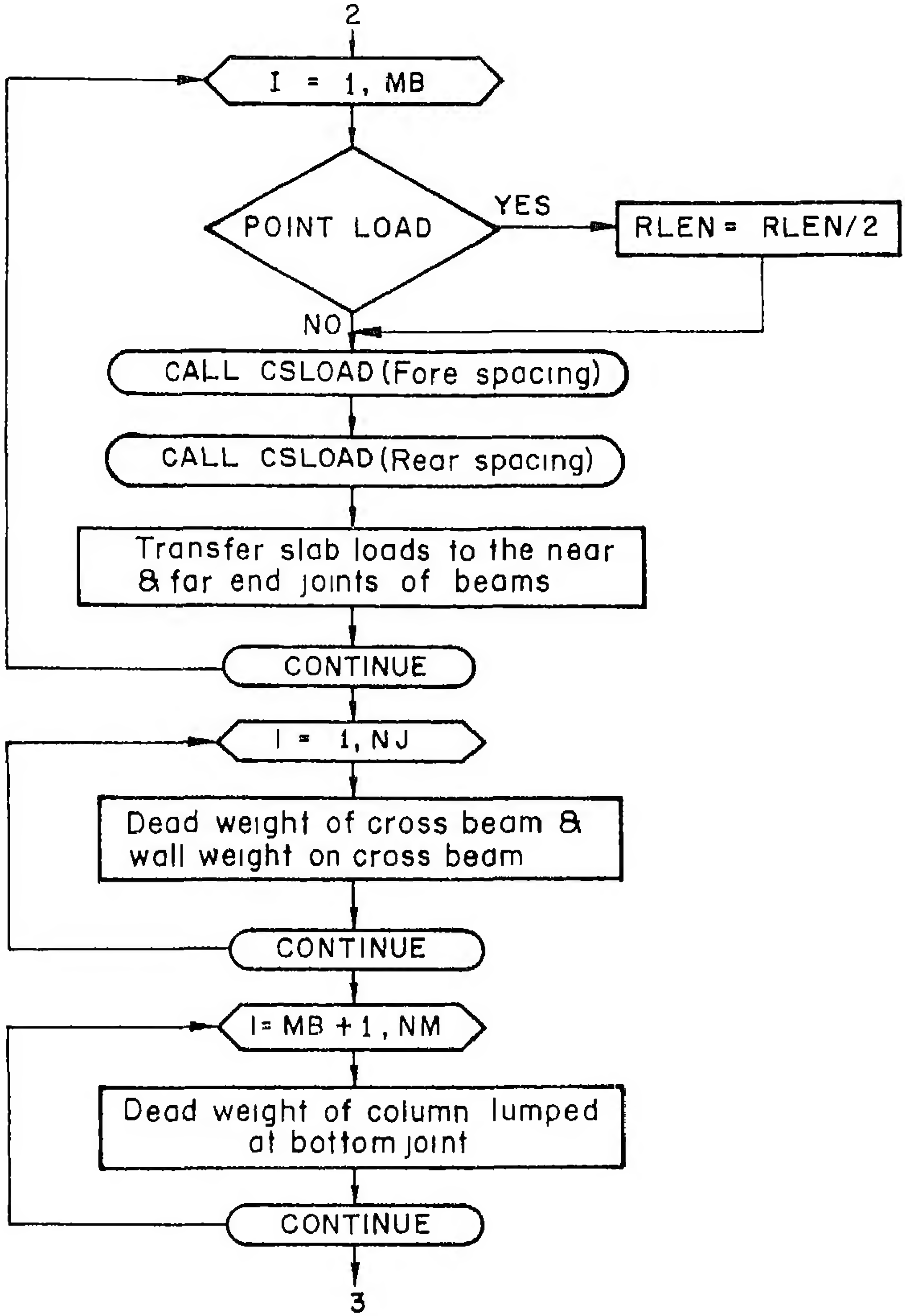


Fig. 2.12 Flow chart for generation of joint loads.

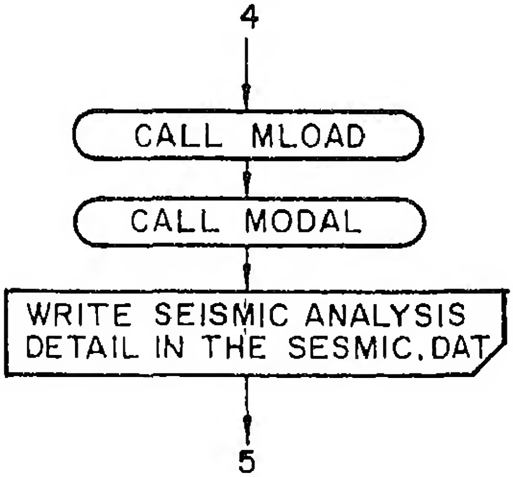


Fig 2.13 General flow chart for Seismic analysis

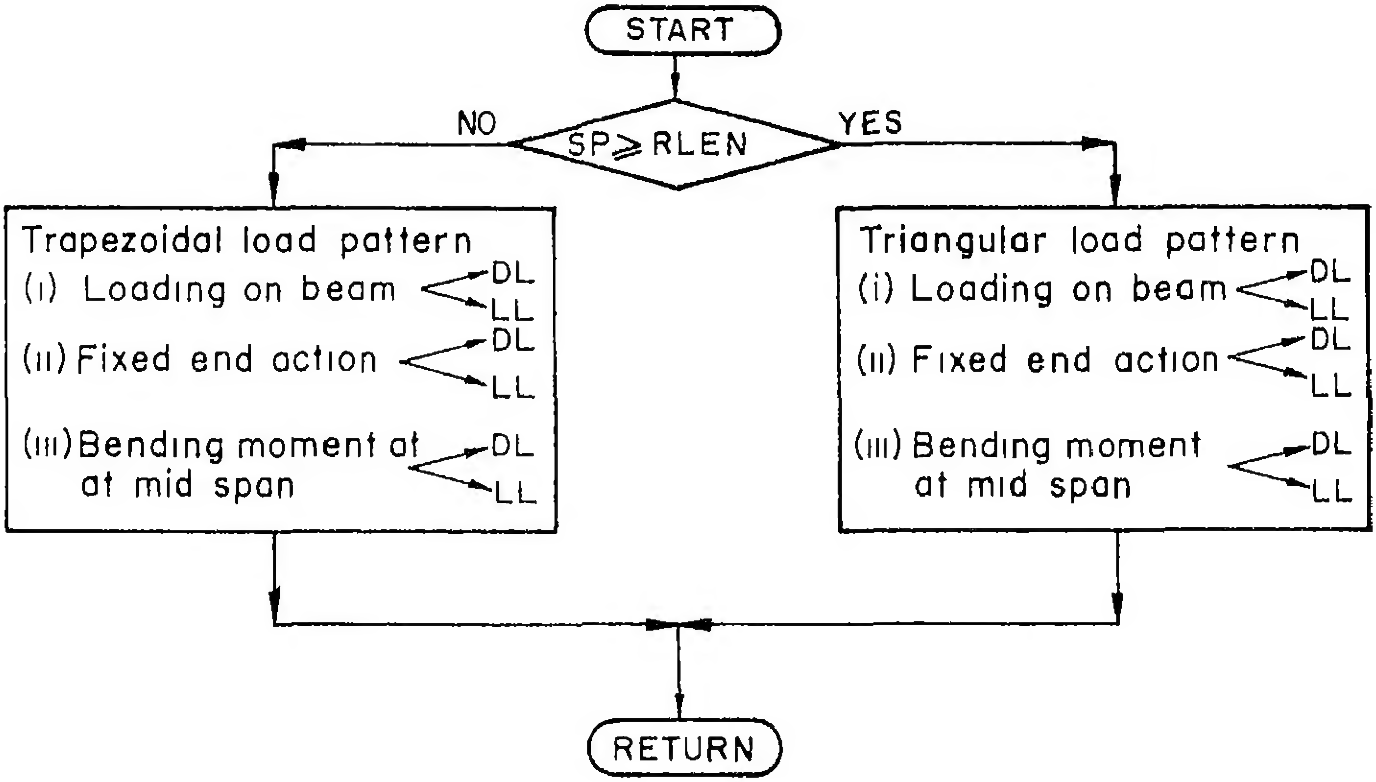


Fig 2.14 General flow chart of subroutine 'SUDL'

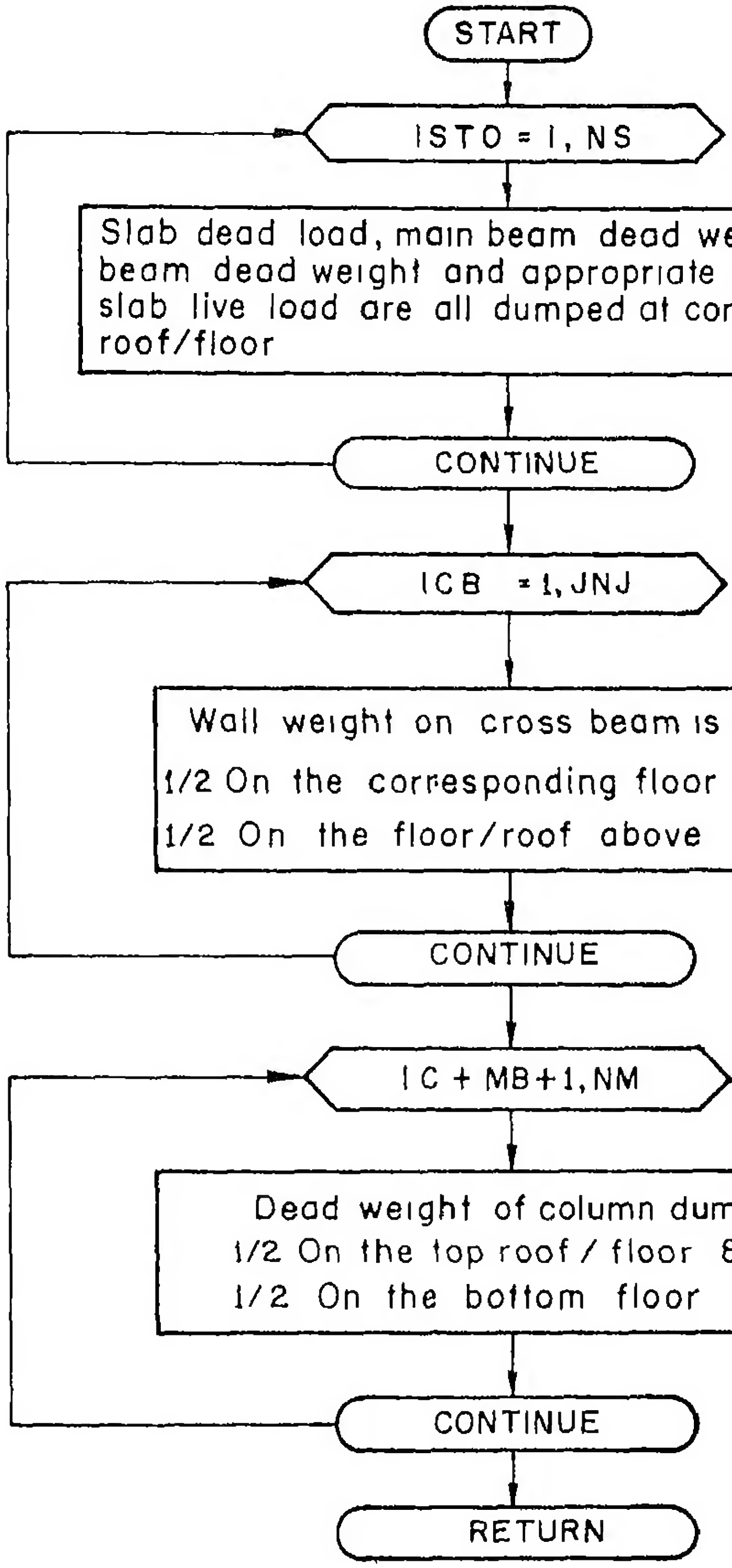


Fig. 2.15 General flow chart of subroutine "MLOAD"

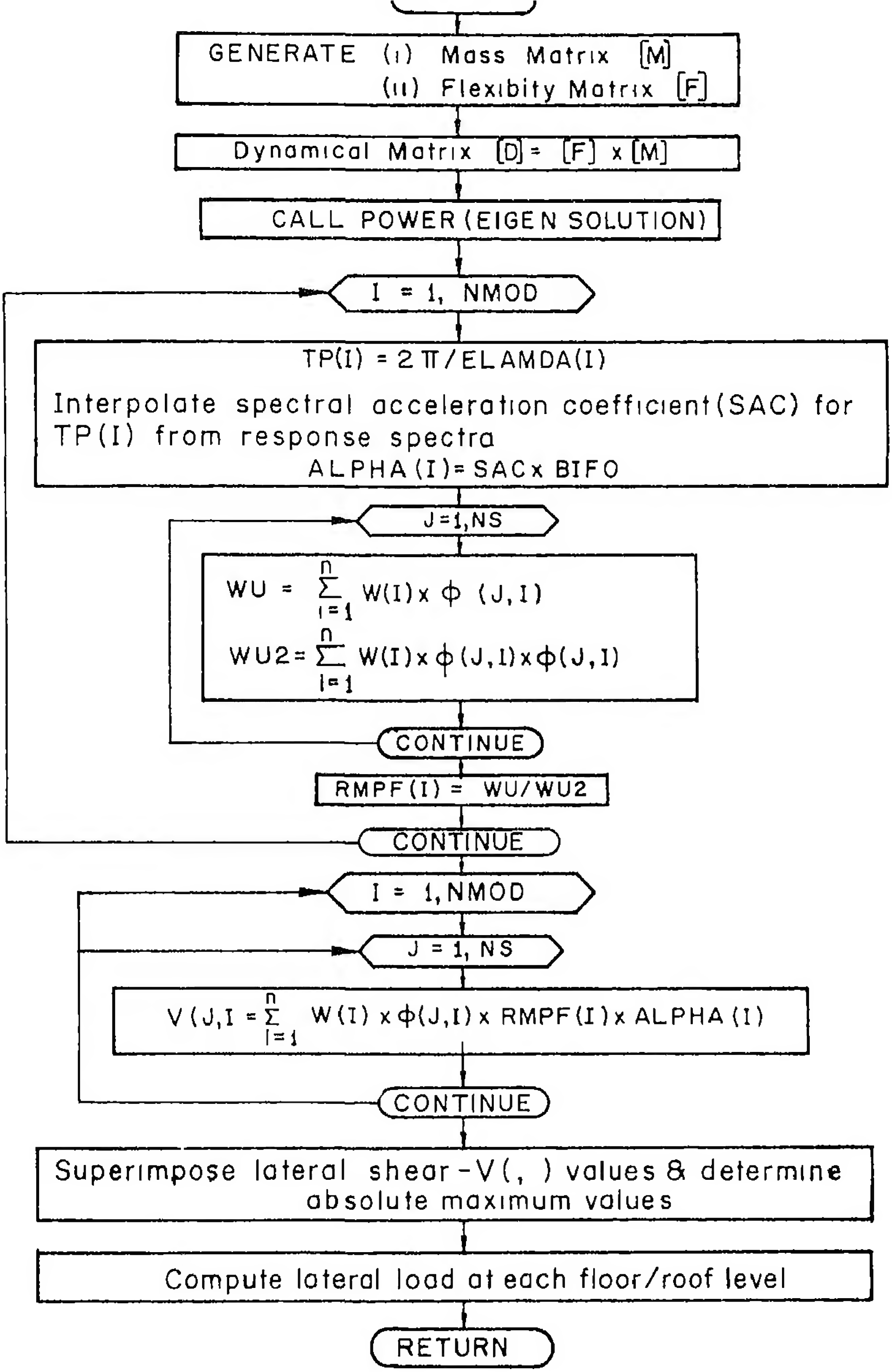


Fig. 2.16 General flow chart for subroutine MODAL

VECLEN is not attempted The references have been quoted in appendix The book "Applied Numerical Methods" by Carnaham et al[3] provides intensive and clear explanations for these numerical techniques

2.12 MODAL ANALYSIS (Summary)

The Indian standard code on earthquake resistant design of structures IS 1893 - 1984 permits/reccommends Modal analysis using Response-spectrum method for buildings upto 90 m in height in all seismic zones For buildings having irregular shape and/or irregualr distribution of mass and stiffness, the code reccommends the designer to carry out modal analysis using response spectrum only

Procedure adopted for modal analysis in present work

1 The total floor/roof weights are computed and the corresponding mass matrix [M] is generated

2 Total storey stiffness is determined and the flexibility matrix [F] generated.

3 Dynamical matrix [D] is computed using the relation -

$$[D] = [F] \times [M]$$

4 Dynamic response is determined by normal mode theory using "POWER METHOD" for eigen solution. The time period, and mode shape coefficients at various levels for 3 modes are computed

5 Interpolate for spectral acceleration from the Average Acceleration Spectra corresponding to appropriate time period and damping (5% of critical) for the 3 modes Determine the horizontal seismic coefficient

6 The mode participation factors for 3 modes are computed

7 Determine the lateral shear forces at each roof/floor level for 3 modes and superimpose to arrive at the absolute maximum values

8. Compute the lateral load to be applied at each floor/roof level from the absolute maximum values of lateral shears (see fig 2.16 for flow chart showing details of calculations)

2.13 INPUT/OUTPUT ILLUSTRATION :

The input data is to be typed in a file name DAT2 INP in a format free environment The details of input data cards is shown in Table 2 3, with appropriate data card numbers The table is self explanatory, but some specific terms & symbols and their details are noted below -

Data cards 1 & 2 are title cards The various symbols given in card numbers 3 & 4 are listed as under

ISYS		Working system of units	= 1 (SI units) = 2 (MKS units) = 3 (FPS units)
NLC	·	Number of load combinations (maximum = 3)	
IELWL	:	NO EL or WL analysis EL analysis WL analysis	= 0 = 1 = 2
LLRED	:	Live load reduction	= 0 (NO) = 1 (YES)
NJEXL		Number of joints with extra loads	
NBDOT	:	Number of beams with point loads	
ISETB	:	Set number of bars to be used in beams	
ISETC		Set number of bars to be used in columns	

INTRAC	Option for interaction during analysis	= 0 (NO) = 1 (YES)
LONG	Slenderness effects in columns during design	= 0 (WSD) = 1 (LSD)
UBRK	Density of wall material	
PPT	Height of parapet on roof	
EQF	Factor used for distribution of lateral loads to match horizontal deflection of frames	
BIFO *	Factor which depends upon soil type, importance of structure and earthquake zone (explained below in detail)	
FL	Fraction of Live load probable to be present during earthquake	

* BIFO = BETA x I x FO

Table 2 5 (a,b,c) gives values of these three factors to be chosen as per provisions of IS 1893 - 1984 .

Output files are presented in chapter 4

TABLE 2.3 DETAILS OF DATA CARDS : (DAT2 INP)

Card Number	I N P U T D A T A
1	TITLE Card (column nos 1 - 60)
2	Row Number (column nos. 1 - 5)
3	ISYS, NLC, IELWL, LLRED, NJEXL**, NBDOT, ISETB, ISETC, INTRAC, LONG, JOK(1)
4	UBRK, PPT, EQF, BIFO, FL, JOK(2)
5	Load factors (FDL(I), FLL(I), FEL(I), I = 1, NLC), JOK(3)
6	Thickness of slab (SLBTK(I), I = 1, MB), JOK(4)
	Live Load on slab (RLIV(I), I = 1, MB), JOK(5)
	Wall thickness (WLTK(I), I = 1, MB), JOK(6)
	Beam size (WIDE(I), I = 1, MB), JOK(7) (DEEP(I), I = 1, MB), JOK(8)
	Column size (WIDE(I), I = MB+1, NM), JOK(9) (DEEP(I), I = MB+1, NM), JOK(10)
7	Cross wall thickness & avg cross beam size (CWWT(I), I = 1, JNJ), CWIDE, CDEEP, JOK(11)
8	Point loads · Optional card (IF NBDOT > 0) Beam Numbers with point loadings, JOK(12)
9	Extra joint loads . Optional card (IF NJEXL > 0) J, DJ1,DJ2,DJ3, RLJ1,RLJ2,RLJ3, JOK(13)
9 + 1	. . . ., ...
	... ., ...
9+NJEXL	J, DJ1,DJ2,DJ3, RLJ1,FLJ2,RLJ3, JOK(13)
10 + NJEXL	Wind loads · Optional card (IF IELWL = 2) Lateral wind loads at each floor/roof level starting from top . ——> +ve,JOK(14)

** NJEXL This option is useful for reading extra loads at joints due to canopy projections, lift loads & other such loads The constants written in card number 9 to (9+NJEXL) are listed below -

J = Number of the joint with extra loads
DJ1 = Horizontal load at the joint due to DL (right +ve)
DJ2 = Vertical load at the joint due to DL (down +ve)
DJ3 = Moment acting on the joint due to DL (clockwise +ve)
RLJ1, RLJ2 & RLJ3 are corresponding values for LL

TABLE 2.4 EXAMPLE PROBLEM DAT2 INP

Card Number	I N P U T D A T A
1	EXAMPLE PROBLEM FOR ILLUSTRATION, IIT Kanpur,1988
2	ROW B
3	1, 3, 1, 0, 2, 3, 3, 5, 0, 0, 999
4	19 2, 1 0, 1 0, 0 20, 0 50, 999
5	1 5,1 5,0 0, 1 2,0 6,1 2, 1 2,0 6,-1 2, 999
6	2x0.20, 17x0 18, 999
	2x4 0, 4 0, 2x5 0, 6x5 0, 5x6 0, 3x5 0, 999
	19x0 20, 999
	19x0 250, 999 19x0.400, 999
	27x0 300, 999 27x0 750, 999
7	0 .0 12, 12 12 12 2, 2 .12 12 2, 2 .12 12 2, .12 2 12 12 2 12, 2 2 12 12 2 2, 25 35, 999
8	17, 18, 19, 999
9	22, 0 33 -50 , 0 17 -25 , 999
10	27, 0 33 50 , 0 17. 25 , 999

TABLE 2 5 (a) BETA values for diff soil-foundation systems

SL NO	FOUNDATION SYSTEM	BETA values for soil *		
		TYPE I	TYPE II	TYPE III
1	Piles passing through any soil but resting on soil of TYPE I	1 0	1 0	1 0
2	Piles not covered in sl no 1	---	1 0	1 2
3	Raft foundations	1 0	1 0	1 0
4	Combined or Isolated footings with Tie Beams	1 0	1 0	1 2
5	Isolated footings without Tie Beams	1 0	1 2	1 5
6	Well foundations	1 0	1 2	1 5

* Soil TYPE I ·· Rock or Hard soils
Soil TYPE II . Medium soils
Soil TYPE III Soft soils

TABLE 2 5 (b) Values of Importance factor - "I"

SL NO	Type of Multistoreyed building	Values of "I"
1	Important service and community structures, such as hospitals, shcools, important power houses, monumental structures; emergency buildings like telephone exchange, large assembly structures like cinemas, assembly halls & subway stations	1 50
2	All others	1 00

TABLE 2.5 (c) Values of Seismic zone factors FO

SL NO	ZONE Number	Seismic zone factor "FO"
1	I	0 05
2	II	0 10
3	III	0 20
4	IV	0 25
5	V	0 40

CHAPTER 3 : ANALYSIS AND DESIGN

3.1 General : In this chapter the third and fourth modules are presented in two seperate parts The first part deals with Analysis and the second part deals with the Design of Beams, Columns and Footings

PART I A N A L Y S I S

3.2 Introduction : The well known stiffness method is an obvious choice for analysis Stiffness matrix in its banded form is made use in the present work The input data to this module is completely generated by the preprocessors In special cases if interactive mode is opted for, then the programme makes some enquiries in the interactive mode There are two occasions when interactive mode could be opted , viz,

(i) To alter cross section and/or characteristic strengths of member if the Design program suggests redesign

(ii) To alter fixed end actions in members in rare circumstances when beams are subjected to unusual type of loadings

For the dead & live load analysis, the stiffness matrix remains the same and hence is assembled only once, whereas for analysis of frame for earthquake/wind loads, the stiffness matrix is to be reassembled due to change in boundary conditions The frame is

idealized as hinged at base for gravity loads, and fixed at base for lateral loads

The displacement solutions are obtained using "Modified Cholesky Method" which is an extension of the Cholesky square root method The flow charts available in the book by Weaver and Gere <21> have been used to find the displacement solutions

After conducting the DL, LL & EL/WL (if any) analysis, the superimposition of displacements and forces for different load combinations is done

An important attribute of this program is the "Reduction of Live Load effects in Columns". This is done as per the suggestions in IS . 875 - 1964, and is optional from the users view point

3.3 <u>Analysis of plane frame</u> The building frame is idealised as a 2-D plane frame and is discretised into elements (beams and columns) between the connecting nodes (joints). The displacements associated with the joints are translations in X & Y directions and rotation in the Z sense

The possible displacements at a joint 'j' are

3j-2 = index for translation in X direction
3j-1 = index for translation in Y direction
3j = index for rotation in the Z sense

The number of degrees of freedom 'ND' in a plane frame is given by ND = 3 NJ - NR, where 'NJ' is the number of joints & 'NR' is

the number of restraints A typical plane frame member with indexes for possible joint displacements in their positive sense are shown in fig. 3 1 The orthogonal set of axes x, y & z shown in the fig 3 1 are the reference axes for the structure hence-forth referred as the 'structure axes'. The typical displacements in a plane frame member for member oriented axes x_m, y_m & z_m are given in fig 3 2 (a), in their positive directions The 6 x 6 stiffness matrix for the member axes given in fig 3 3(a) is generated for a i^{th} member The next step is transforming member stiffness matrix - $[S_{M}]_i$ to the structure sitffness matrix - $[S_{MS}]_i$ Fig 3 2 (b) indicates the 6 possible displacements at the ends of a member 'i' in directions of structure axes The rotation transformation matrix - $[R]_i$ for a plane frame member shown in fig 3 3 (b) is used for the transformation given by the relation

$$[S_{MS}] = [R]_i^T \; [S_{M}]_i \; [R]_i$$

Appropriate elements from matrix $[S_{MS}]_i$ are transferred to the overall joint stiffness matrix In the present work code numbering is used to directly generate the joint stiffness matrix - $[S_{FF}]$ corresponding to free joint displacements only The upper band of the stiffness matrix is generated & stored in a rectangular array

The next phase in analysis is, construction of load vectors.

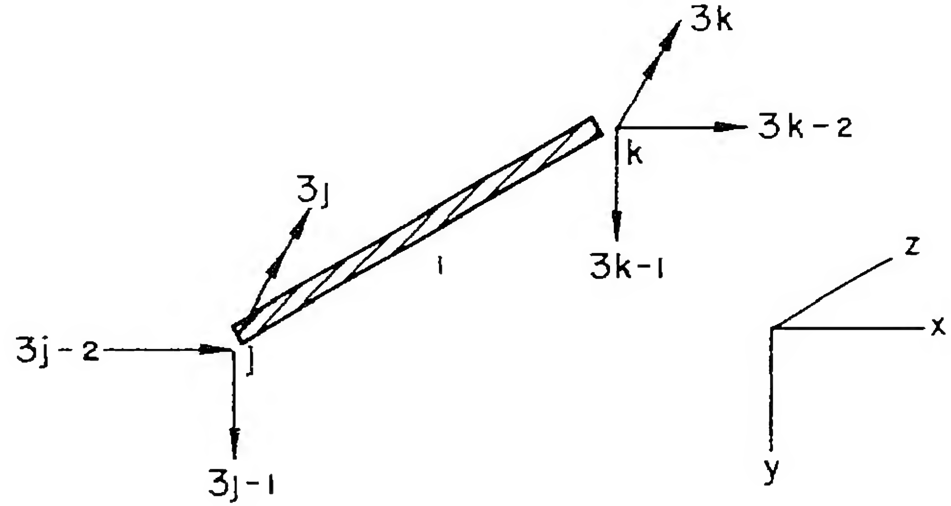
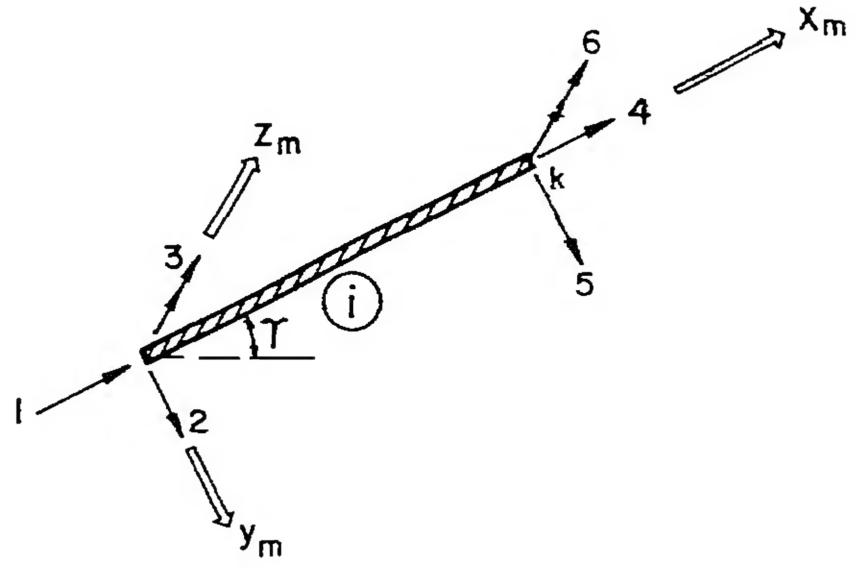
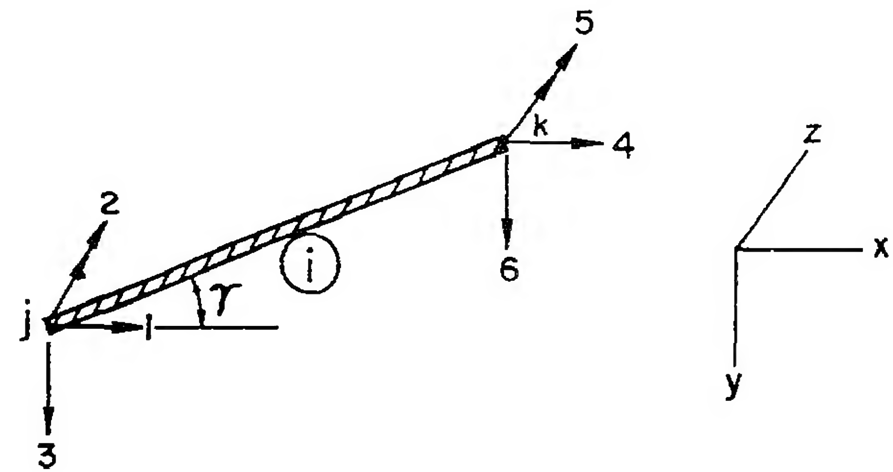


Fig 3.1 End displacements in a plane frame member



(a) Orientation about member axes



(b) Orientation about structure axes

Fig. 3.2 Plane frame element

$$
[S_M]_i = \left[\begin{array}{ccc|ccc}
\frac{EA_x}{L} & 0 & 0 & \frac{-EA_x}{L} & 0 & 0 \\
0 & \frac{12EI_z}{L^3} & \frac{6EI_z}{L^2} & 0 & \frac{-12EI_z}{L^3} & \frac{6EI_z}{L^2} \\
0 & \frac{6EI_z}{L} & \frac{4EI_z}{L} & 0 & \frac{-6EI_z}{L} & \frac{2EI_z}{L} \\
\hline
\frac{-EA_x}{L} & 0 & 0 & \frac{EA_x}{L} & 0 & 0 \\
0 & \frac{-12EI_z}{L^3} & \frac{-6EI_z}{L^2} & 0 & \frac{12EI_z}{L^3} & \frac{-6EI_z}{L^2} \\
0 & \frac{6EI_z}{L^2} & \frac{2EI_z}{L} & 0 & \frac{-6EI_z}{L^2} & \frac{4EI_z}{L}
\end{array}\right]
$$

Fig 3.3(a) Plane frame member stiffness matrix for member axis

$$[R]_i = \begin{bmatrix} C_x & C_y & 0 & 0 & 0 & 0 \\ -C_y & C_x & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_x & C_y & 0 \\ 0 & 0 & 0 & -C_y & C_x & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Fig 3.3(b) Rotation transformation matrix

External actions applied at joints constitute the vector A_J. Fig 3.4 shows the positive actions at a typical joint in a plane frame. The fixed end actions created due to member loads are transformed into equivalent joint loads - A_E (see fig 3.5, all actions given in the figure are in the positive directions.)
The vectors A_J and A_E are added to arrive at the combined joint load vector A_C (rearranged to form A_{FC})

After the generation of all the necessary matrices is accomplished, the free joint displacements D_F (which is expanded to D_J) are solved for using the relation

$$[D_F] = [S_{FF}]^{-1} [A_{FC}]$$

The final member end actions are also computed using the relation

$$AM_i = A_{MLi} + S_M R_i D_{Ji}$$

The equations for the 3 member end actions corresponding to the j^{th} end of the member are given below :-

Here :- $j1 = 3j - 2$, $j2 = 3j - 1$; $j3 = 3j$
$k1 = 3k - 2$, $k2 = 3k - 1$, $k3 = 3k$

$$(AM)_{1,i} = (AML)_{1,i} + EA_{xi}/L_i \{[(D_J)_{j1} - (D_J)_{k1}]C_{xi}$$
$$+ [(D_J)_{j2} - (D_J)_{k2}]C_{yi}\}$$

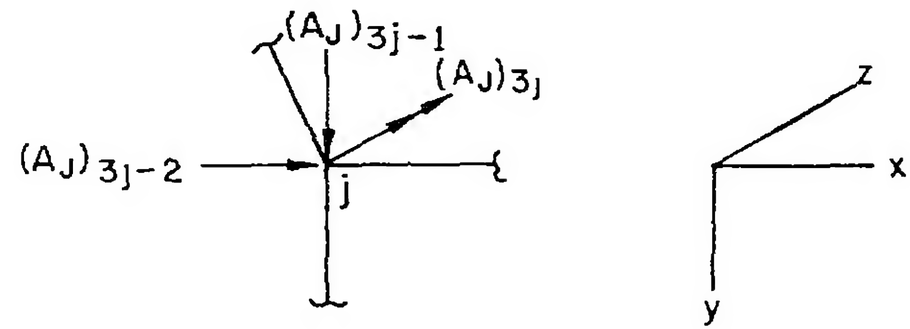


Fig 3 4 Joint loads for a plane frame

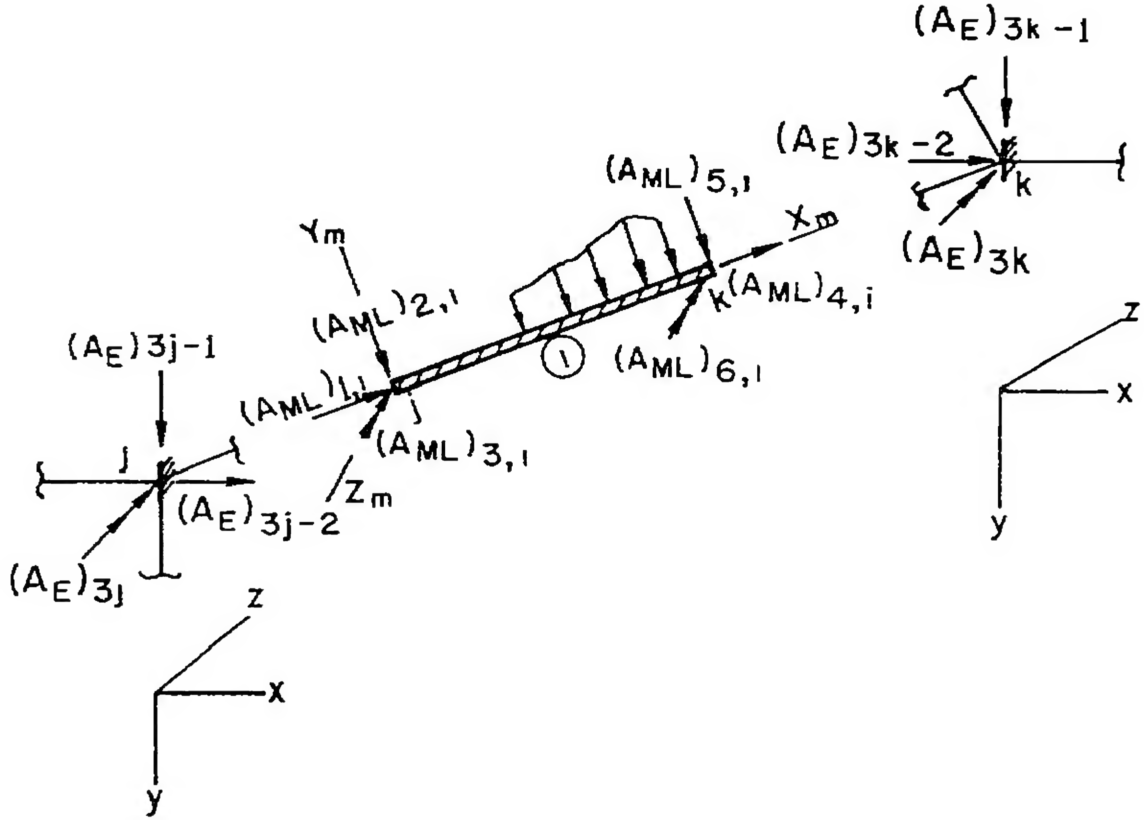


Fig. 3.5 Loads on a plane frame member

$$(AM)_{2,i} = (A_{ML})_{2,i} - 12EI_{zi}/L_i^3 \,([(D_J)_{j1} - (D_J)_{k1}]C_{yi}$$

$$- [(D_J)_{j2} - (D_J)_{k2}]C_{xi})$$

$$+ 6EI_{zi}/L_i^2 \,[(D_J)_{j3} + (D_J)_{k3}]$$

$$(AM)_{3,i} = (A_{ML})_{3,i} + 6EI_{zi}/L_i^2 \,(-[(D_J)_{j1} - (D_J)_{k1}]C_{yi}$$

$$+ [(D_J)_{j2} - (D_J)_{k2}]C_{xi})$$

$$+ 4EI_{zi}/L_i \,[(D_J)_{j3} + 5(D_J)_{k3}]$$

The corresponding values at the k^{th} end are arrived at on similar lines

3.4 <u>The significant aspects of the analysis program are</u> -

Name of the program	A N A L Y
Program size	640 lines (total)
Subroutines	THREE 1 BANFAC 2 BANSOL 3 LCOMB
Input data :	Interface files created by preprocessors (ANALD.TEM, ANALL TEM & ANAL1 TEM)

Output data	Displacements and Member actions in file = ANAL.DAT
Generated data used in design	1 File = DESN TEM (member properties) 2 Files= LC1 TEM LC2.TEM LC3 TEM (diff load combiantions)

The general flow chart of the analysis module is shown in fig.3.6 .

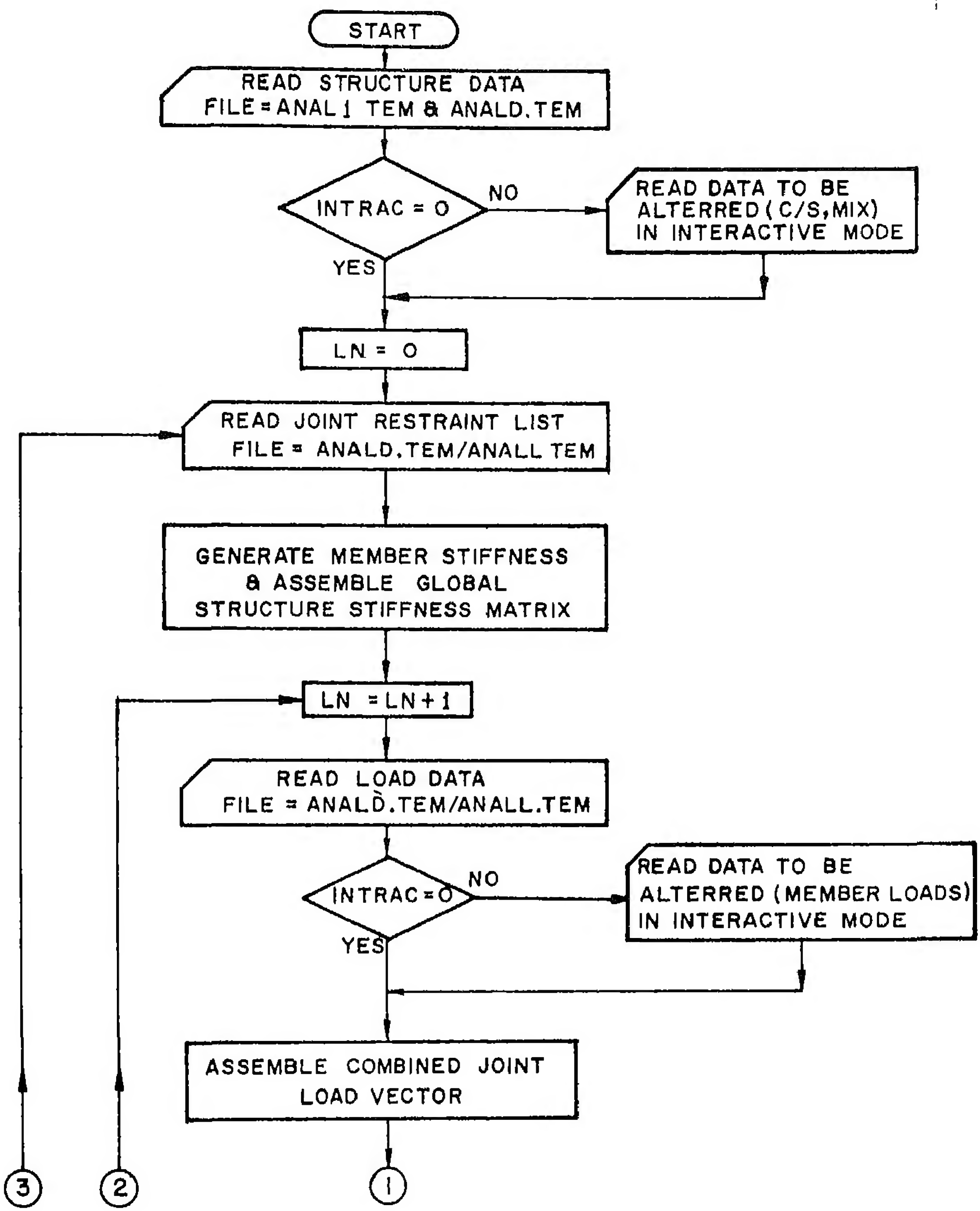


Fig 3.6 (a) General flow chart of analysis program

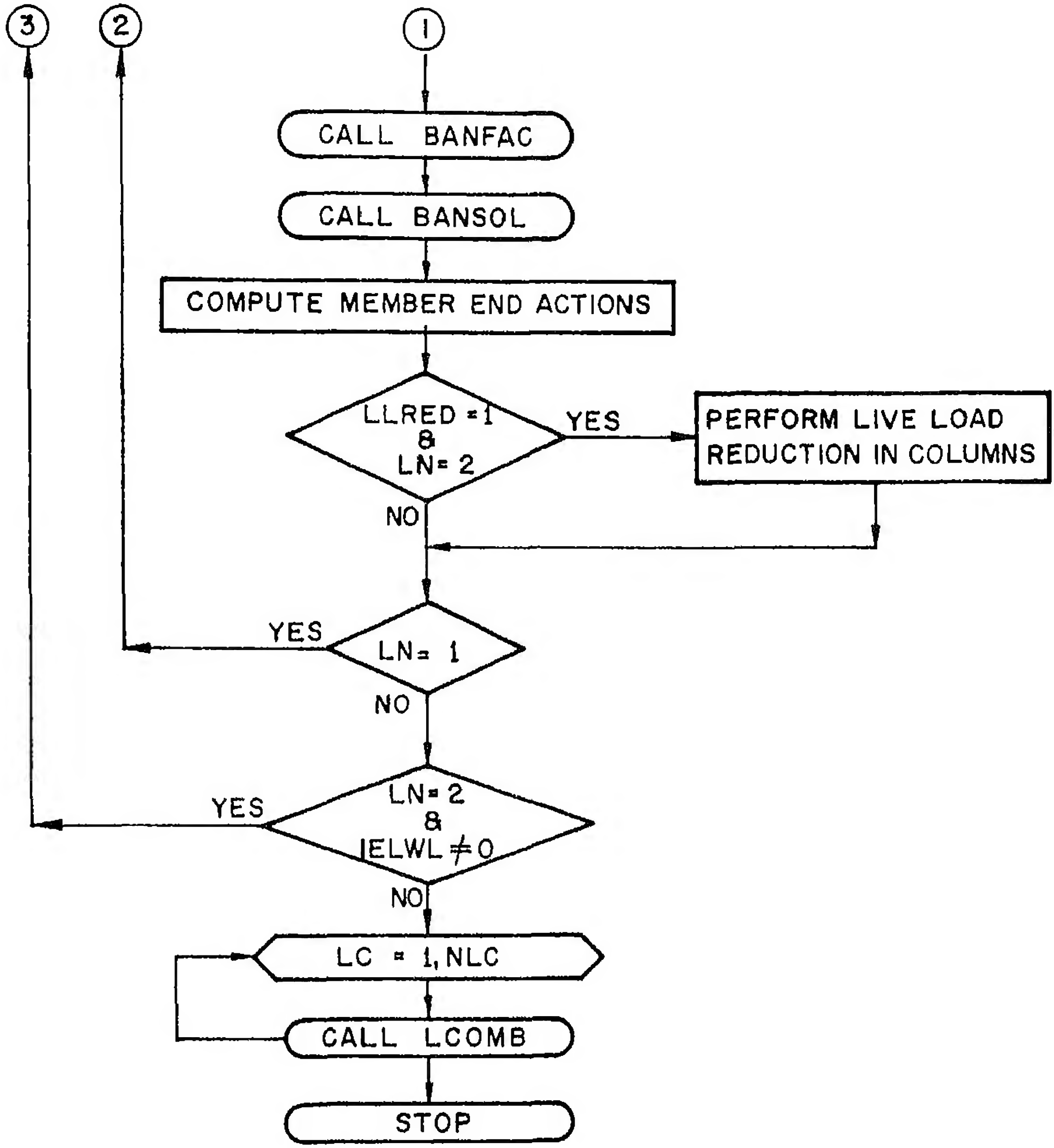


Fig 3.6(b) General flow chart of analysis program

PART II DESIGN

3.5 General : The process of engineering design might be characterised as a cyclic combination of data gathering and decision making Data gathering often requires high technical competence and analytical capabilities the importance in decision making distinguishes the engineer from both the scientist and the technician. Design decisions are based on the problem, factors that influence problem and the engineer's knowledge, intuition and experience.

Present work . In a multistoreyed RCC building frame, the main components to be designed are beams, columns and foundations The design module is executed in two stages viz,

(i) Design of Beams & Columns

(iii) Design of Footings

(i) DESIGN OF BEAMS AND COLUMNS

3.6 Introduction Limit state design approach is adopted for the design of all the components (IS : 456 - 1978) No fresh input data is to be fed during this stage, as the interface files will provide the necessary input. Design decisions are called for during footing design and hence an input file is to be fed at this stage

The program suggests ReDesign ('RD') if any members violates the

design limitations. Design limitations are basedontwo basic criterion viz, (i)provisions of IS 875 - 1978 (ii)practical limitations Redesign messages appear on the screen, as well as in the output file

The members are designed for each load combination consecutively and the design requirements alterred to suit the worst combination.

The design module has a data bank for different sets of bar diameters and the corresponding areas Two subroutines BEMBAR & COLBAR are provided for this purpose For a given set of bars to be used in beams and/or columns, these subroutines conduct an iteration and extract the combination which satisfies the design requirement If the design requirement exceeds the maximum avialable data for a particular set in the data bank, the next higher set is choosen automatically The time consuming detailing work is cut down tremendously by this additional feature of the design module. The general flow chart for the design of beams and columns is indicated in fig 3 12

3.7 DESIGN OF BEAMS

Beams are designed as rectangular sections, which may be singly reinfored or doubly reinforced The criterion of design is explained below :-

(a) Singly reinforced sections (see fig 3 7)

$$M_{u,lim} = 36\ x^{u}_{max} /d\ (\ 1\ -\ 42\ x^{u}_{max} /d\ )\ bd^{2}\ f_{ck}$$

$$(x^{u}_{max} /d) = 0035\ /\ (\ 0035 + 002 + 87 f_{y} /E_{s}\ )$$

$M_{u,lim}$ > or = M_{u} , the section is designed as a singly reinforced beam The design area of steel can be found by considering the moment equilibrium at the cross section -

$$M_{u} = 87\ f_{y}\ A_{st}\ d\ (\ 1\ -\ A_{st}\ f_{y}\ /\ (b\ d\ f_{ck}\ )\ )$$

Min. and max areas of reinforcement

Min area of tensile steel > or = $0.85\ b\ d\ /\ f_{y}$

Max. area of tensile steel > or = $02\ b\ D$

(b) Doubly reinforced section (see fig 3 8)

Compression reinforcement becomes inevitable when the depth of the beam is restricted and a signly reinforced section becomes inadequate. The section is designed as doubly reinforced when

$M_{u,lim}$ < M_{u}

The area of compression steel required to carry the extra bending moment is given by the relation

$$M_{u} - M_{u,lim} = f_{sc}\ A_{sc}\ (\ d\ -\ d_{c}\ )$$

The total area of tensile steel $A_{st} = A_{st1} + A_{st2}$

A_{st1} = area of tensile steel as for a signly reinforced beam section for $M_{u,lim}$

$$A_{st2} = A_{sc}\ f_{sc}\ /\ (\ 87 f_{y}\ )$$

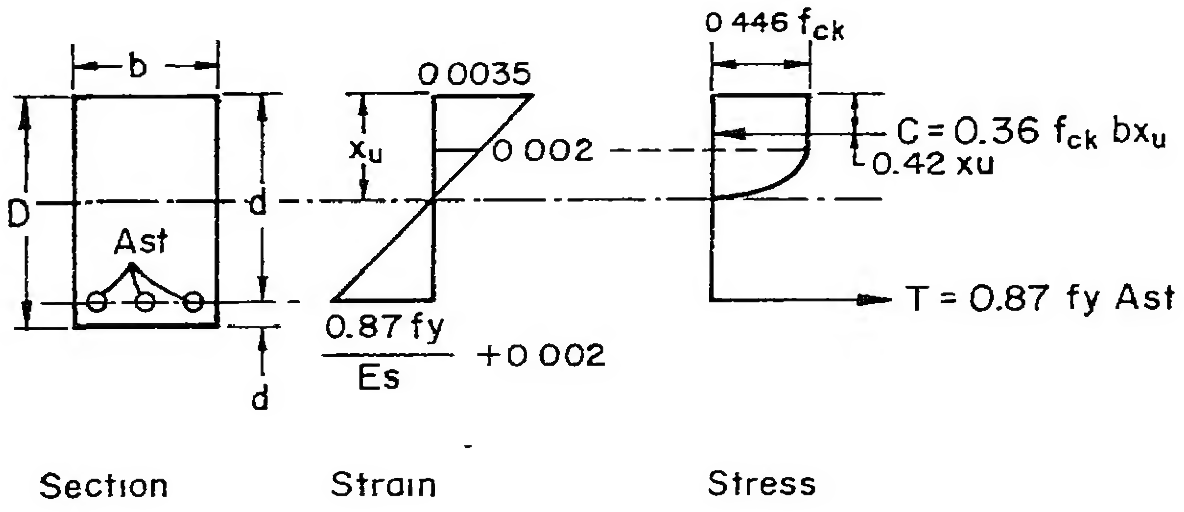


Fig 3.7 Stress block parameters. Singly reinforced section

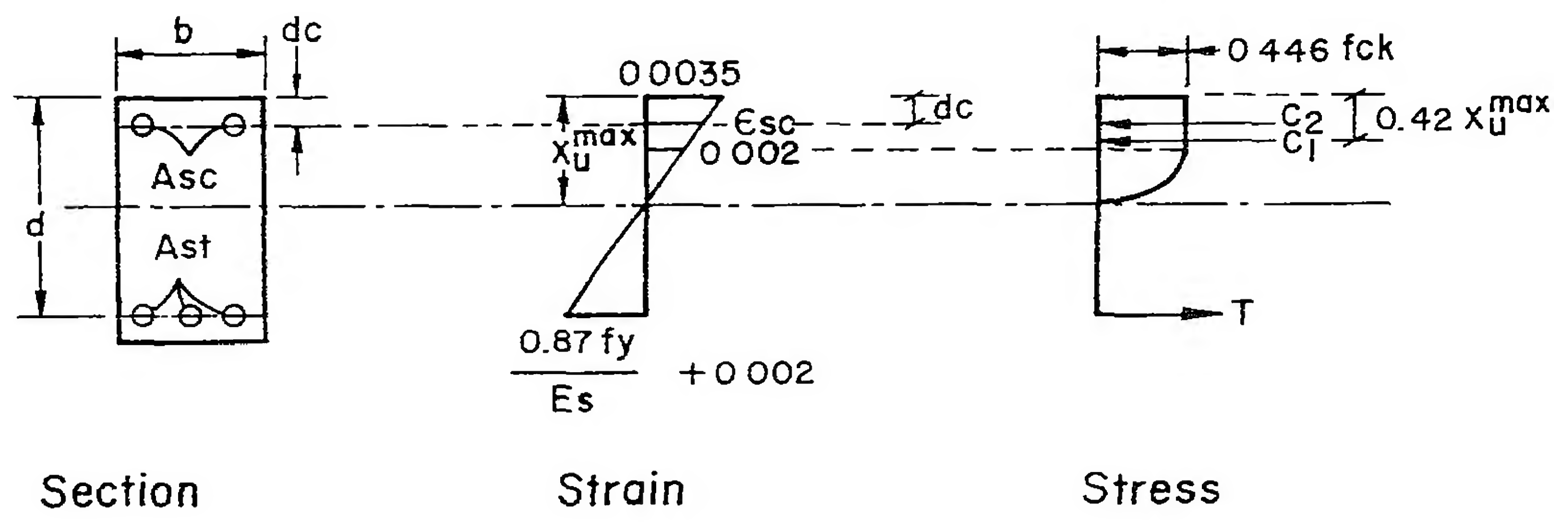


Fig.3.8 Stress block parameters· Doubly reinforced section

Min. & max. reinforcement

The min & max tensile reinforcement are same as in a singly reinforced beam sections

Max area compression steel = 0 02 b D

At points of continuity the maximum steel area has been raised to (0.03 b D)

Fig 3.13 provides the General flow chart for the flexural design of beams

(c) Design for Shear

Nominal shear stress $T_v = V_u/bd$ The value of T_v is compared with "T_c" the Design shear strength of concrete and "T_{cmax}" absolute max. shear strength of concrete

if $T_v > T_{cmax}$ . . Redesign

if $T_v > T_c$ . .. design shear reinforcement

if T_v < or = T_c nominal shear reinforcement

Shear reinforcement is provided in the form of vertical stirrups.

Spacing of vertical stirrups $S_v = .87 f_y A_{sv} d / V_{us}$

Shear carried by stirrups $V_{us} = V_u - T_c b d$

Max. spacing is taken as the lesser of :-

(i) $A_{sv} f_{vy} / 4 b$
(ii) 0 75 d
(iii) 450 mm

Min. spacing is limited to 75 mm c/c

Fig 3 14 provides the General flow chart for Shear design of beams and Estimation of material quantities

3.8 DESIGN OF COLUMNS

Columns are designed for axial load and uniaxial bending Design of a column is an iterative process, as the number of unknown quantities supercede the available equilibrium conditions An interaction curve as shown in fig 3 9 is generated for a known percentage of steel relating the two quantities, Axial load (P_u) and Bending moment (M_u)

Interaction curve for P_u and M_u The interaction curve is divided into three regions Points marked 1 - 4 signify that the nuetral axis lies outside section and the column is under pure compression Points marked 5 - 11 signify tensile strain being introduced in the reinforcement which means the nuetral axis lies within the section, but compression controls in this region. Region between points 11 - 12 signifies tension controls region, wherein the tensile steel will have reached its yeild strain The point 12 corresponds to $P_u = 0$ condition

Basic Equilibrium Equations for column design

The equilibrium equations have been derived for the two cases viz,

(i) Nuetral axis lies outside section . (see fig. 3 10)

The constants used in deriving equilibrium equations are explained in the nomenclature given in the beginning

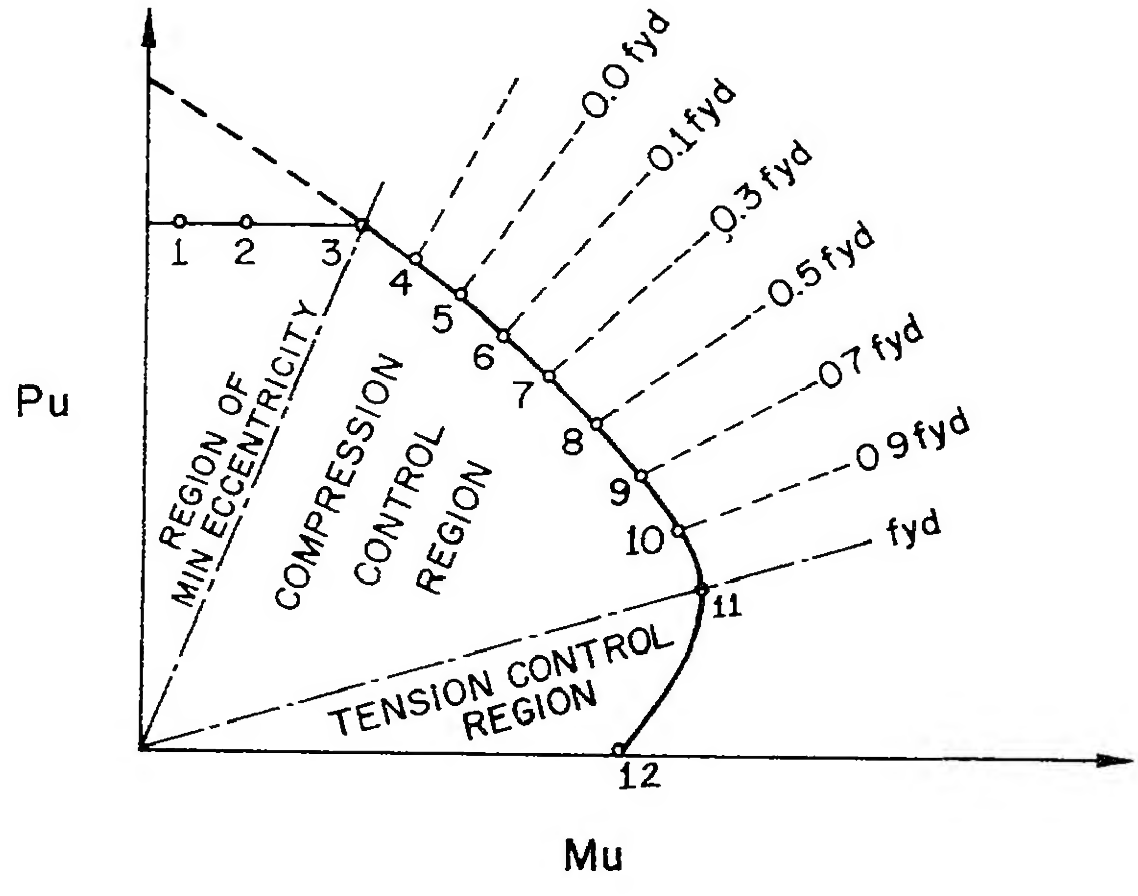


Fig. 3.9 Interaction curve for Mu & Pu

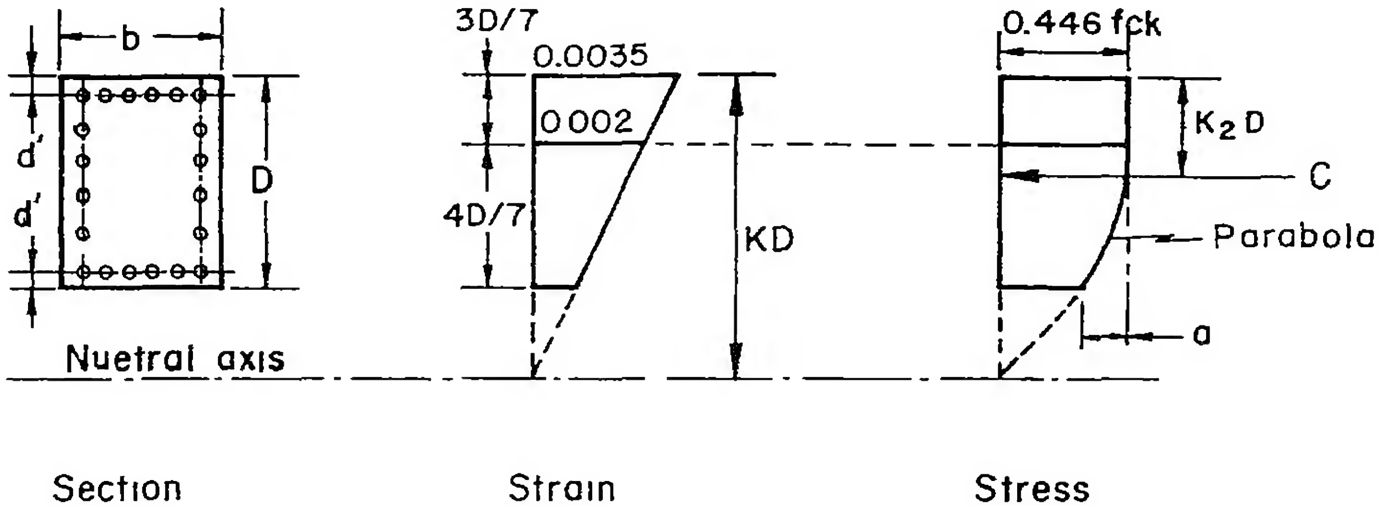


Fig. 3.10 case (i) Stress strain diagrams. K > 1

Force equilibrium results in

$$P_u/f_{ck}\,bD = k_1 + \mathrm{SUM}_{i=1}^{n} [\,(f_{si} - f_{ci})\,(p_i/100\,f_{ck})\,]$$

Moment equilibrium results in

$$M_u/f_{ck}\,bD_2 = k_1(\,5-k_2\,)+\mathrm{SUM}_{i=1}^{n} [\,(f_{si} - f_{ci})(p_i/100f_{ck})(y_i/D)\,]$$

(ii) Nuetral axis lies inside the section (see fig 3 11)

Force equilibrium & Moment equilibrium are

$$P_u/f_{ck}\,bD = 36k + \mathrm{SUM}_{i=1}^{n} [\,(f_{si} - f_{ci})(p_i/100f_{ck})\,]$$

$$M_u/f_{ck}\,bD^2 = 36k(\,5- 42k)+\mathrm{SUM}_{i=1}^{n} [\,(f_{si} - f_{ci})(p_i/100f_{ck})(y_i/D)\,]$$

Max & min reinforcement ·

Min area of steel > or = 0 008 bD

Max. area of steel < or = 0 004 bD

The design steps are presented in the form of flow charts in fig 3.15 (a) & (b)

3.9 <u>The significant aspects of the design program are listed below</u> :-

Name of the program		D E S I G N
Program size	·	700 lines (total)
Surboutines	·	(i) STR415 (ii) BEMBAR (iii) COLBAR
Input data		Interface files 1. DESN.TEM 2. LC1.TEM 3 LC2 TEM 4. LC3 TEM

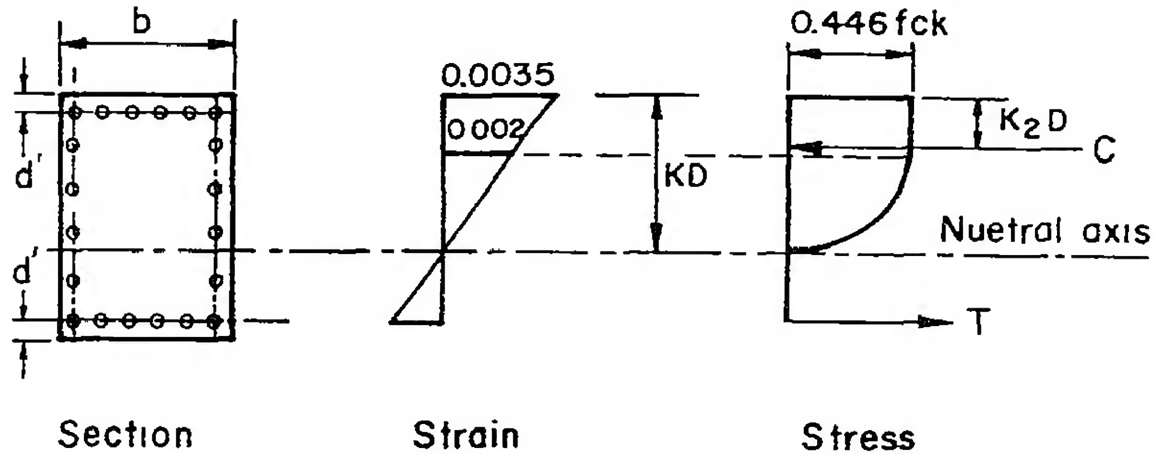


Fig.3.11 case(ii) Stress strain diagrams: $K < 1$

Output data

1 Design requirements in file = DES1 DAT
2 Design details in file = DES2 DAT

SUBROUTINES :

(i) STR415 This subroutine is used to calculate the stress in steel reinforcemtn corresondlng to a particular strain value The stress - strain curve recommended in IS 456 - 1978 have been used for computing stresses at various strain levels

(ii) BEMBAR This is a simple but useful subroutine which has a large data bank of totally nine sets of steel bars Each set has three bar types which are combined effectively to arrive at the design steel area The various sets with their maximum and minimum areas are listed in Table 3 1 -

Table 3 1 Details of Set numbers & Bar types in Beams

SET Number	Bar diameters in "mm"	Min area in "mm2"	Max area in "mm2"
1	10 , 12 , 16	150	800
2	10 , 16 , 20	150	1240
3	12 , 16 , 20	220	1240
4	12 , 16 , 25	220	1470
5	12 , 20 , 25	220	1960
6	16 , 20 , 25	400	3560
7	16 , 20 , 28	400	4920
8	16 , 25 , 28	400	4920
9	20 , 25 , 28	620	4920

The choice of a particular set depends mainly on type of bar available in market and the design requirements If the maximum area available in the data bank does not fulfill the design requirement , the program automatically picks up the next set for that beam only and for the remaining beams the user specified set is used Sets with lower diameter bars are recommended when the beam spans are low and sets with higher diameter bars are to be used for large span beams and heavy loadings.

COLBAR · This subroutine is on identical lines as subroutine BEMBAR , with the exception that this corresponds to column design detailing There are a total of eight sets in the data bank,

whose details are in Table 3 2

Table 3 2 Details of Set numbers & Bar types in columns

SET Number	Bar diameter in "mm"	Minimum area in "mm2"	Maximum area in "mm2"
1	12 , 16 , 20	440	9920
2	12 , 16 , 25	440	15680
3	16 , 20 , 25	800	15680
4	16 , 25 , 28	800	19680
5	20 , 25 , 28	1240	19680
6	20 , 25 , 32	1240	25600
7	20 , 28 , 32	1240	25600
8	25 , 28 , 32	1960	25600

Initial sets are suggested to be used for columns with comparitively low axial loads & smaller cross section Sets 6 , 7 & 8 are recommended for use only in columns with large cross sections and subjected to heavy loadings All the attributes of the subroutine BEMBAR are also present in this subroutine

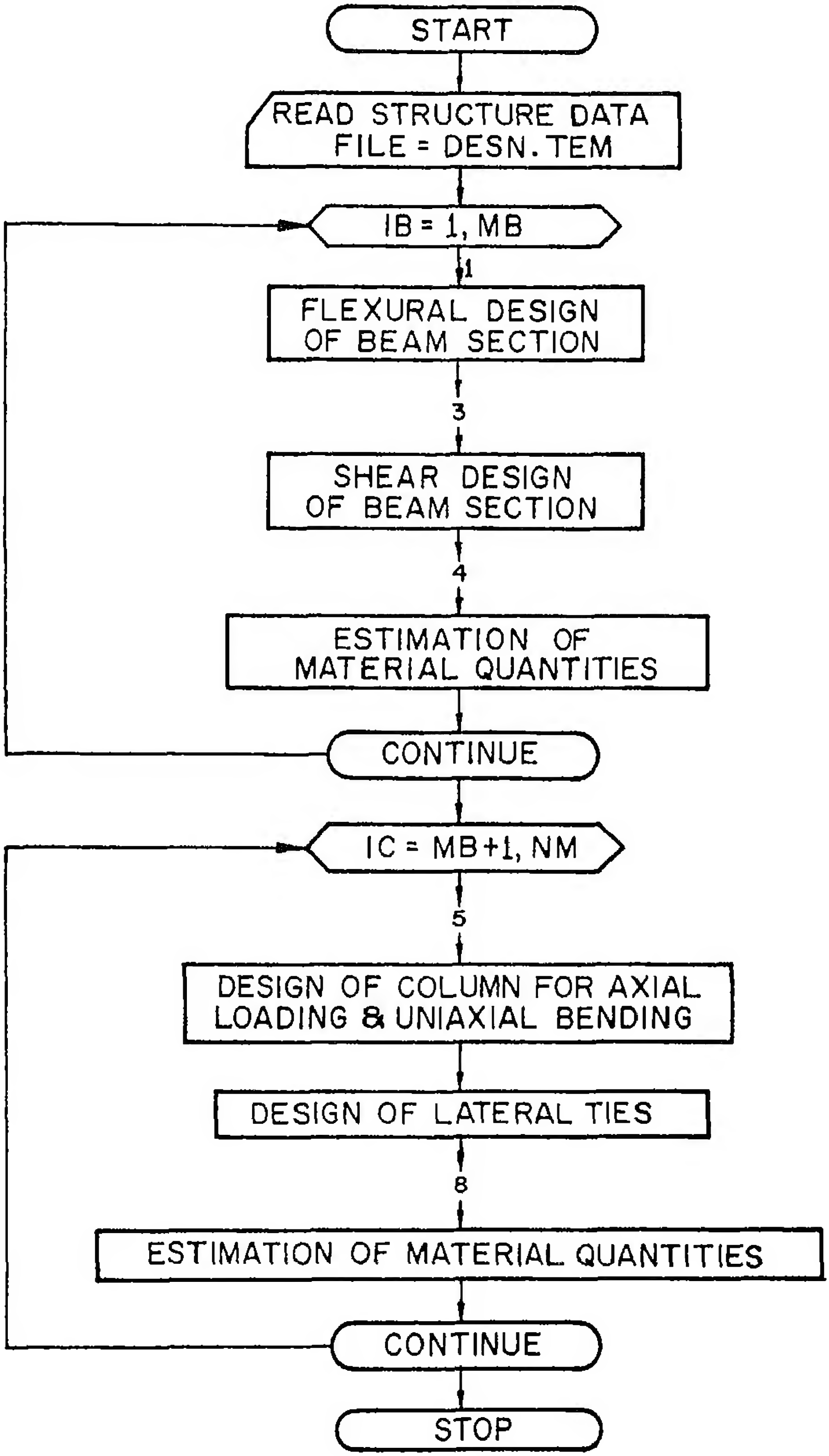


Fig. 3.12 General flow chart for design of beams & columns

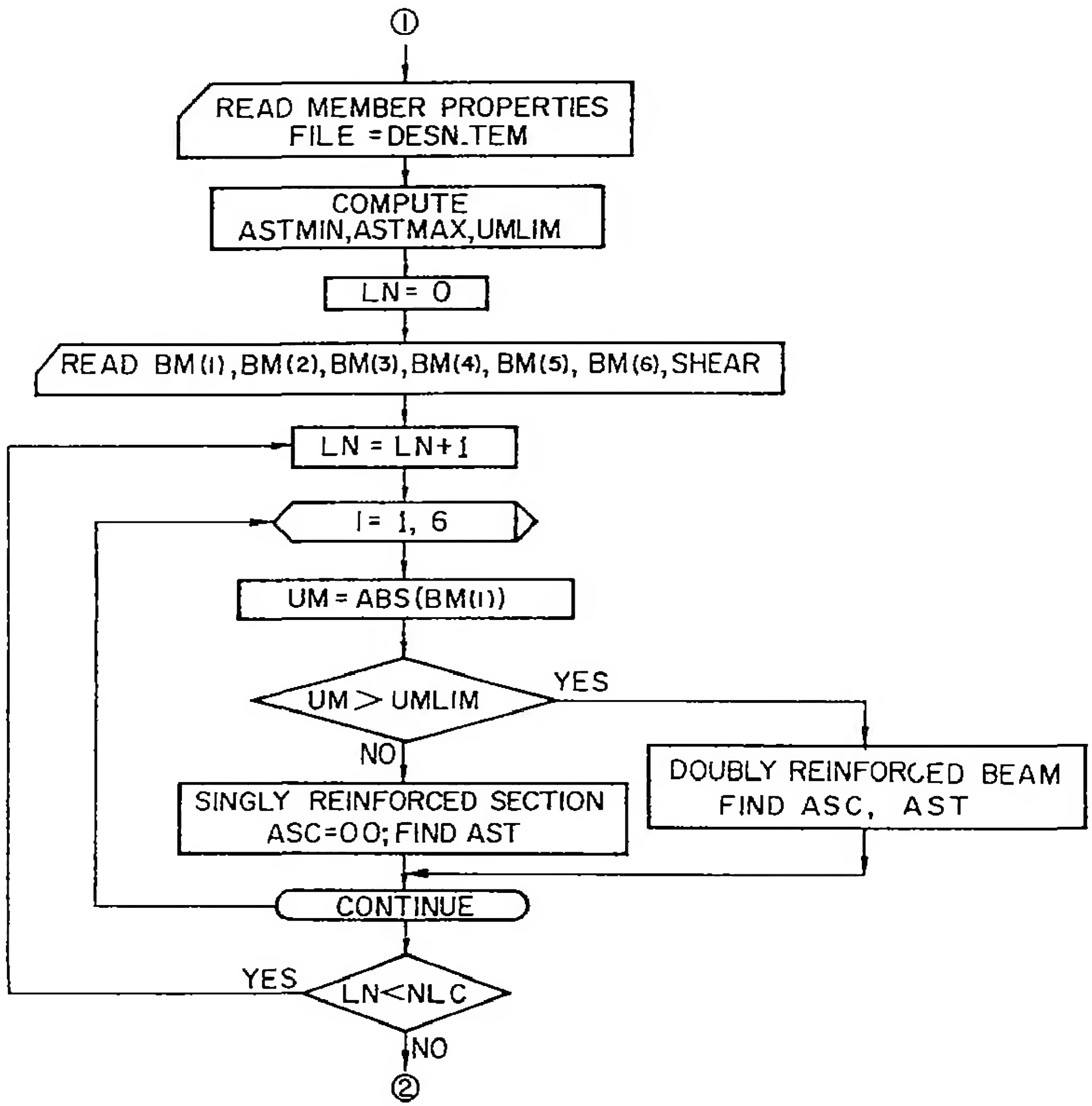


Fig 3.13(a) Flow chart for flexural design of beam

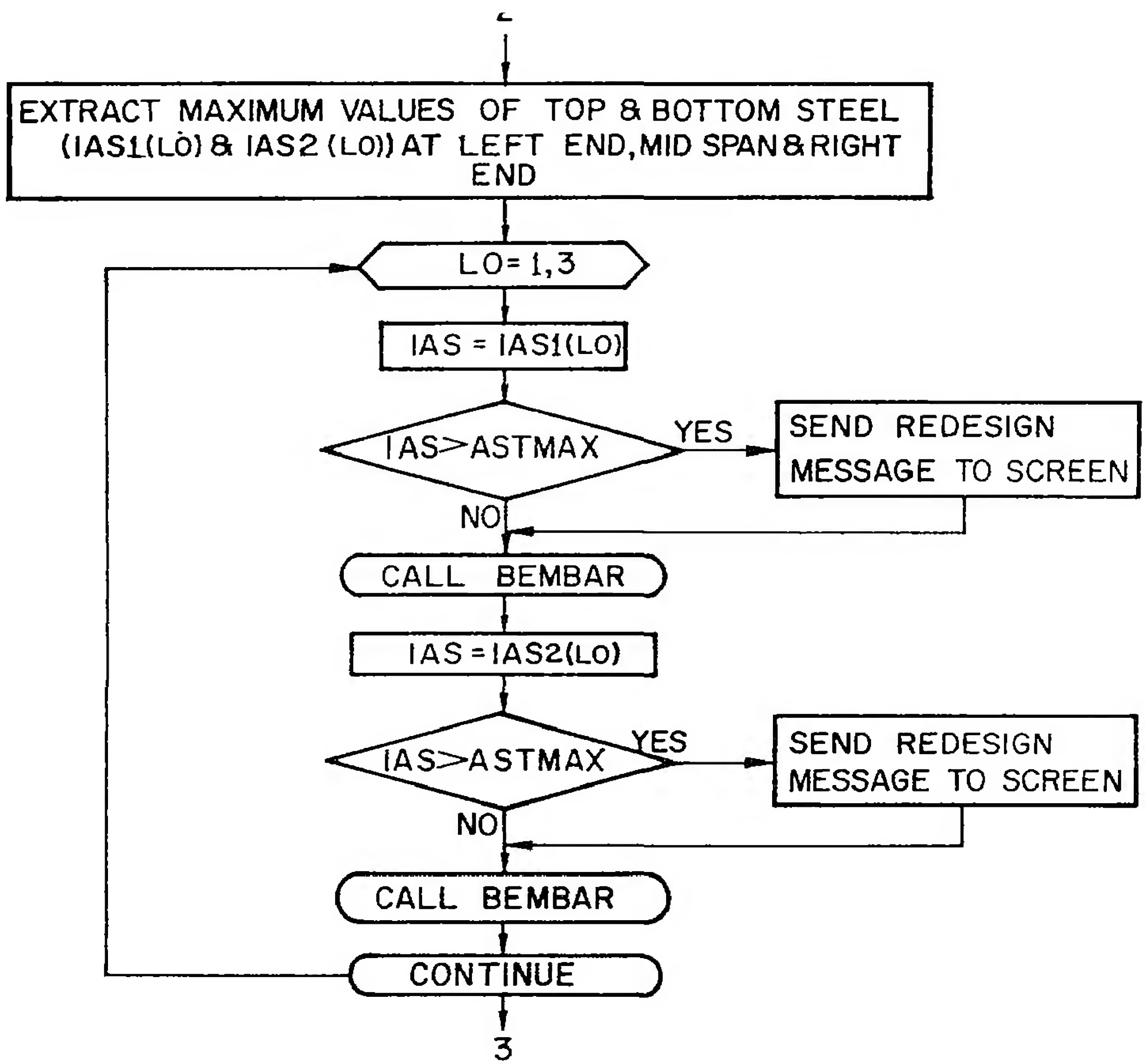


Fig.3.13(b) Flow chart for flexural design of beam

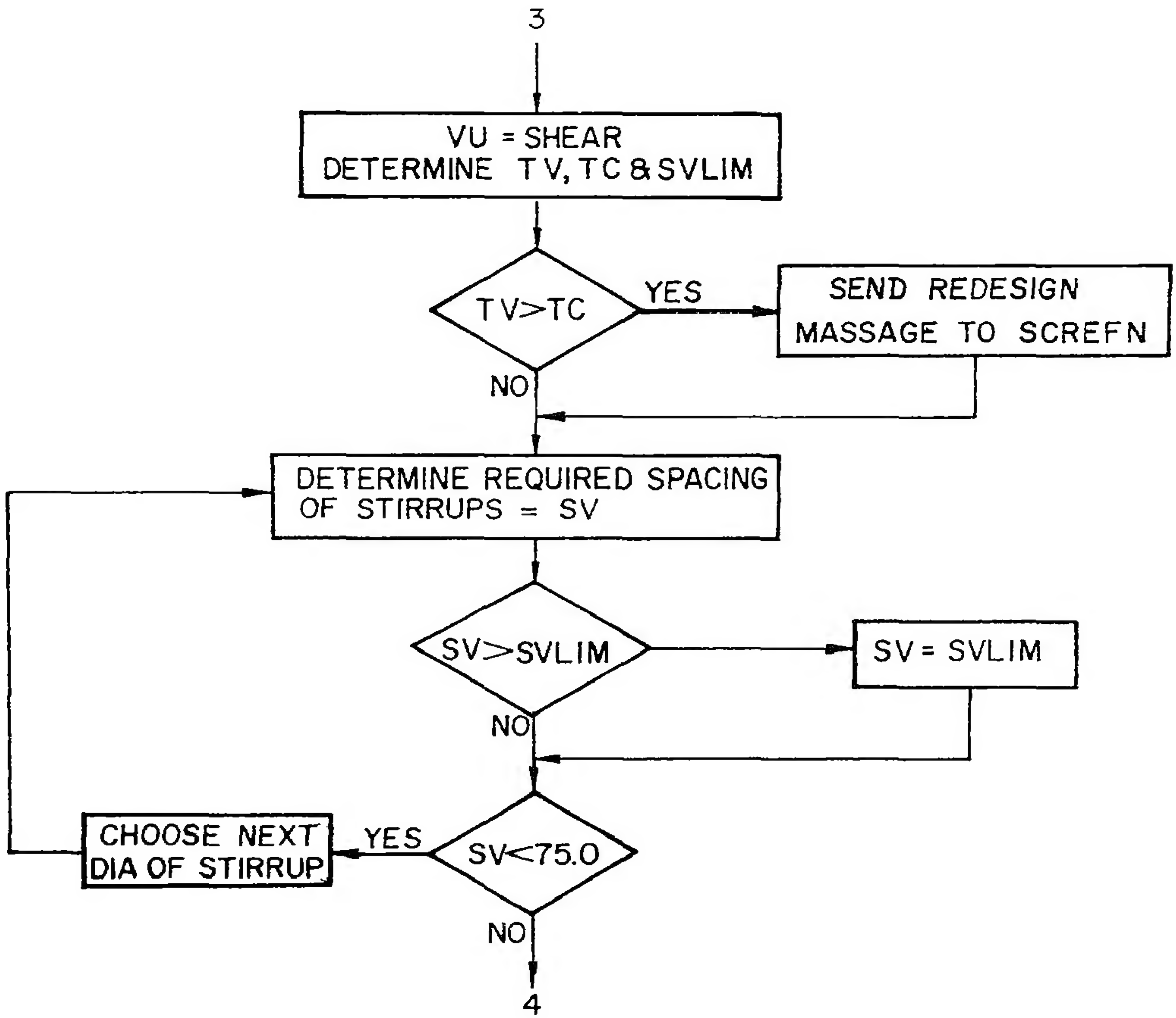


Fig.3.14 Flow chart for shear design of beam.

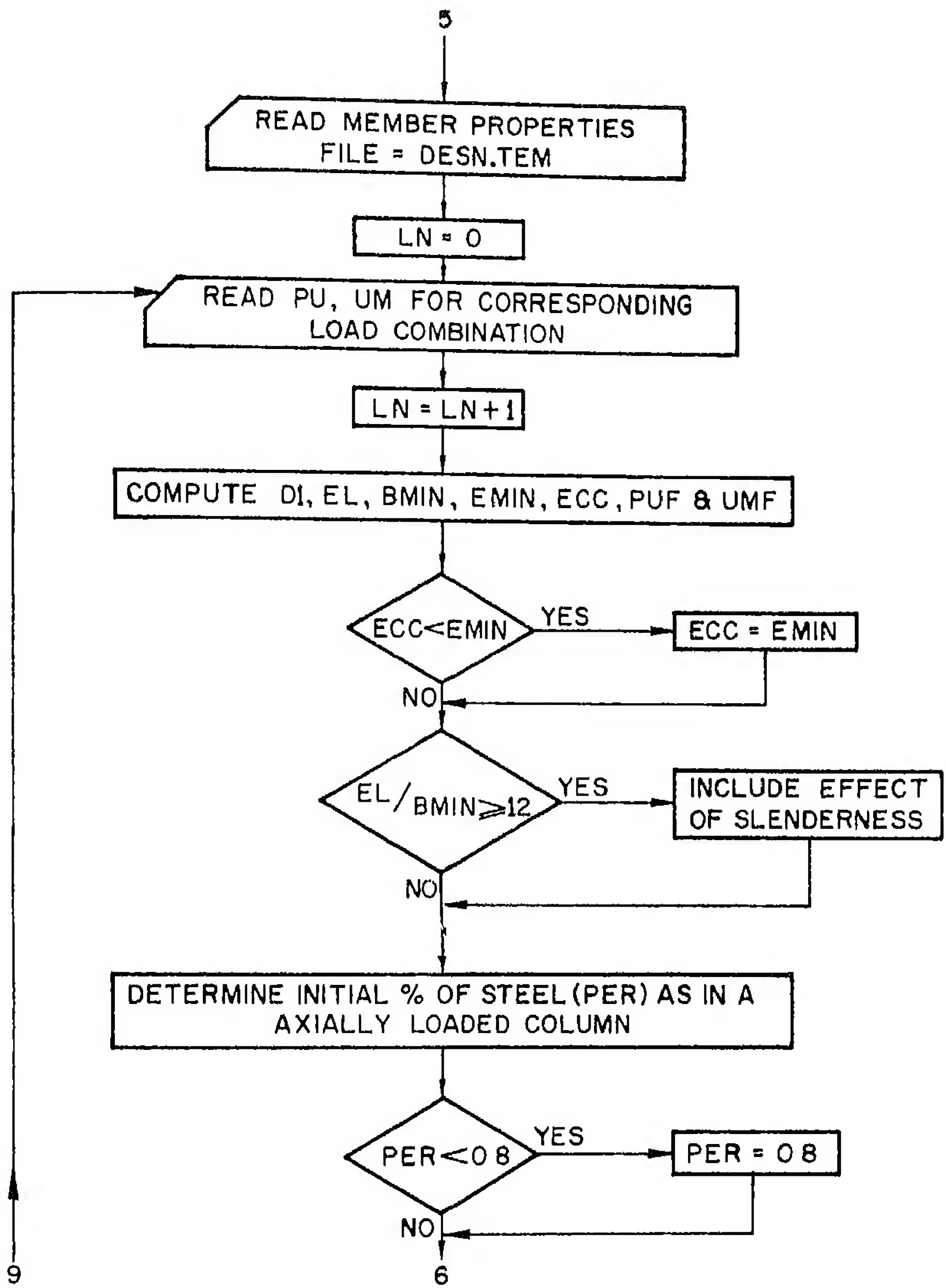


Fig.3.15(a) Flow chart for design of columns.

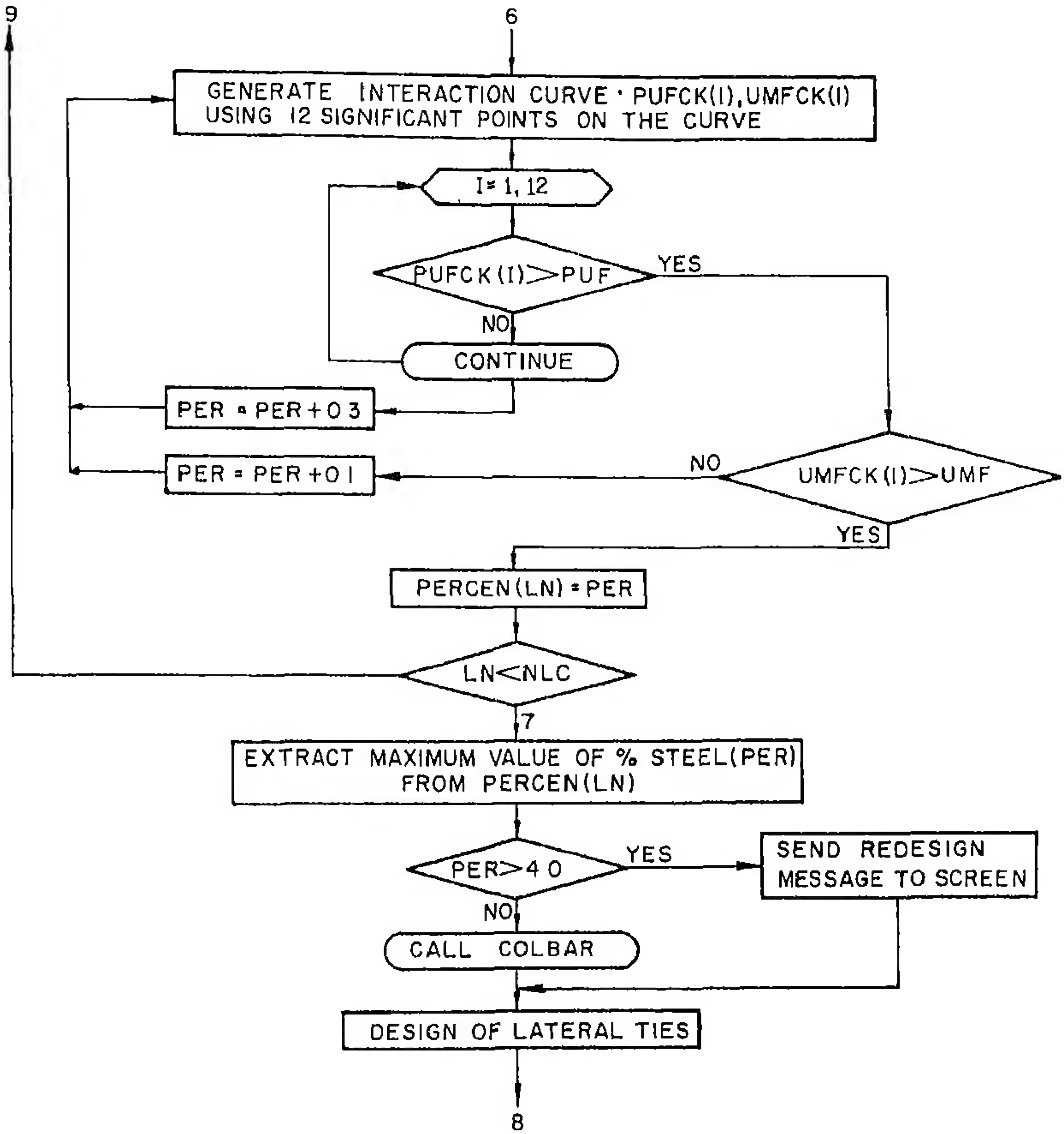


Fig 3 15(b) Flow chart for design of columns

(ii) DESIGN OF FOOTINGS

3.10 Introduction : The foundation systems generally adopted in a tall RC building may be grouped under 4 sub-heads -

(i) Isolated footings

(ii) Combined footings

(iii) Raft foundations

(iv) Deep foundations

Some more information about foundation systems in tall buildings is given in art 1.2 Design of other types of footings is not attempted in the present work Isolated rectangular/square footings will be found to be adequate for framed buildings upto 8-10 storeys in zones of low seismic activity In case of other situations a different foundation sytem may have to be opted for A program has been developed for the design of an isolated tapered footing rectangular/square in plan, satisfying the requirements of IS 456 - 1978 This program is completely independent and fresh input is to be fed for this program

3.11 Design criterion ·

The design of an isolated footing consists of two parts viz, the size & depth of footing. The notations followed in the design of isolated footing is given in fig. 3 16

Area of footing = Design column load / $(SBC)_{soil}$

Square or rectangular footing is designed depending upon the

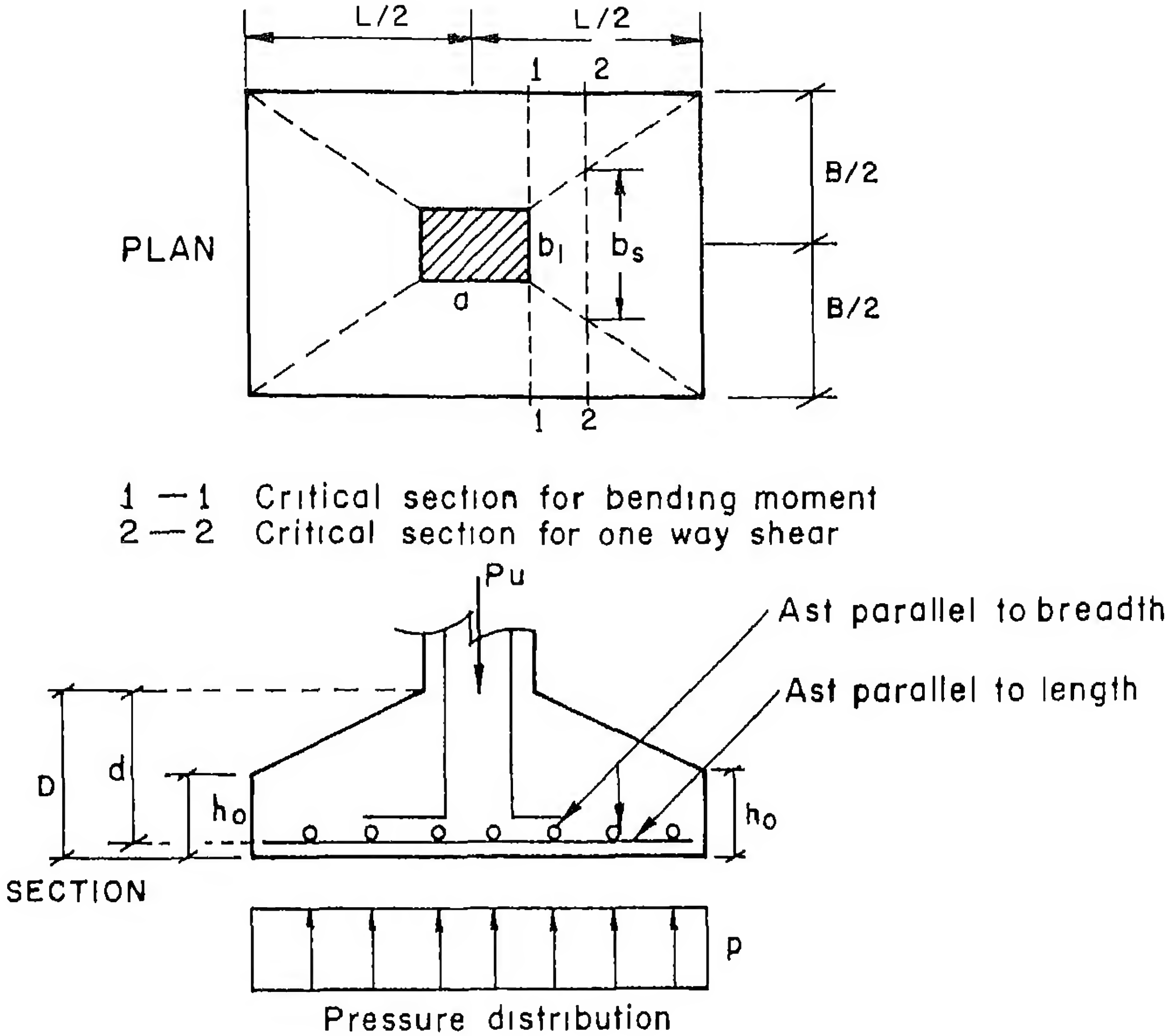


Fig 3.16 Notations for isolated footing with tapering top.

limitations on the maximum dimensions of footing slab.

The moment capacity M_r is given by

$$M_r = ((k_2 - k_1)b + k_2 B)\, d^2 f_{ck}$$

[Reference P Dayaratnam[6]]

For HYSD BARS & Fe415 bars

f_y = 415 MPa , k = 138 , k_2 = 025

Critical section for maximum bending moment 'M_c' is the column face The design condition is that the moment capacity at any section must be more than the moment acting on the section

The area of steel for a trapezoidal section is given by

$$A_{st} = 1.15\, M_c/(jd\, f_y)$$ [Ref P Dayaratnam[6]]

The shear strength of footings is checked for 2 cases, viz, one-way shear action & two-way shear action in accordance with IS · 456 - 1978 . The critical section for shear is located from face of the column at a distance equal to .-

(i) 'd' for one-way shear

(ii) 'd/2' for two-way shear (punching shear)

(i) One-way shear action .

Nominal shear stress $T_v = V_u / b_s d$

where 'b_s' is the width of footing at critical section

T_v < or = the shear strength of concrete (T_c) corresponding to the percentage of tensile steel.

(ii) Two-way shear action ·

Nominal shear stress $T_v = V_u / b_o d$

where 'b_o' is the perimeter of footing at critical section

T_v < or = the corresponding shear strength of concrete given by the relation

$$T_c = [0\ 25\ (f_{ck})^{1/2}]\ k_s$$

$k_s = 0\ 5 +$ (shorter column side)/(longer column side)

k_s < or = 1 0

The reinforcement (A_{tc}) in the central band width is provided in accordance with IS specifications given by

A_{tc} = [2/(1. + B/L)] total steel in short direction

The remainder of the steel is distributed uniformly in the outer portion of the footing.

3.12 <u>The significant aspects of the footing design program are listed as under</u> :-

Name of the program	:	F O T I N G
Program size		125 lines (total)
Subroutines	.	None
Input data	:	Free format in file = FOT INP
Output data		Footing dimensions and Reinforcement details in file = FOT DAT

Input/output files are presented at the end of this chapter A flow chart indicating the general design procedure is shown in fig 3 17 (a & b)

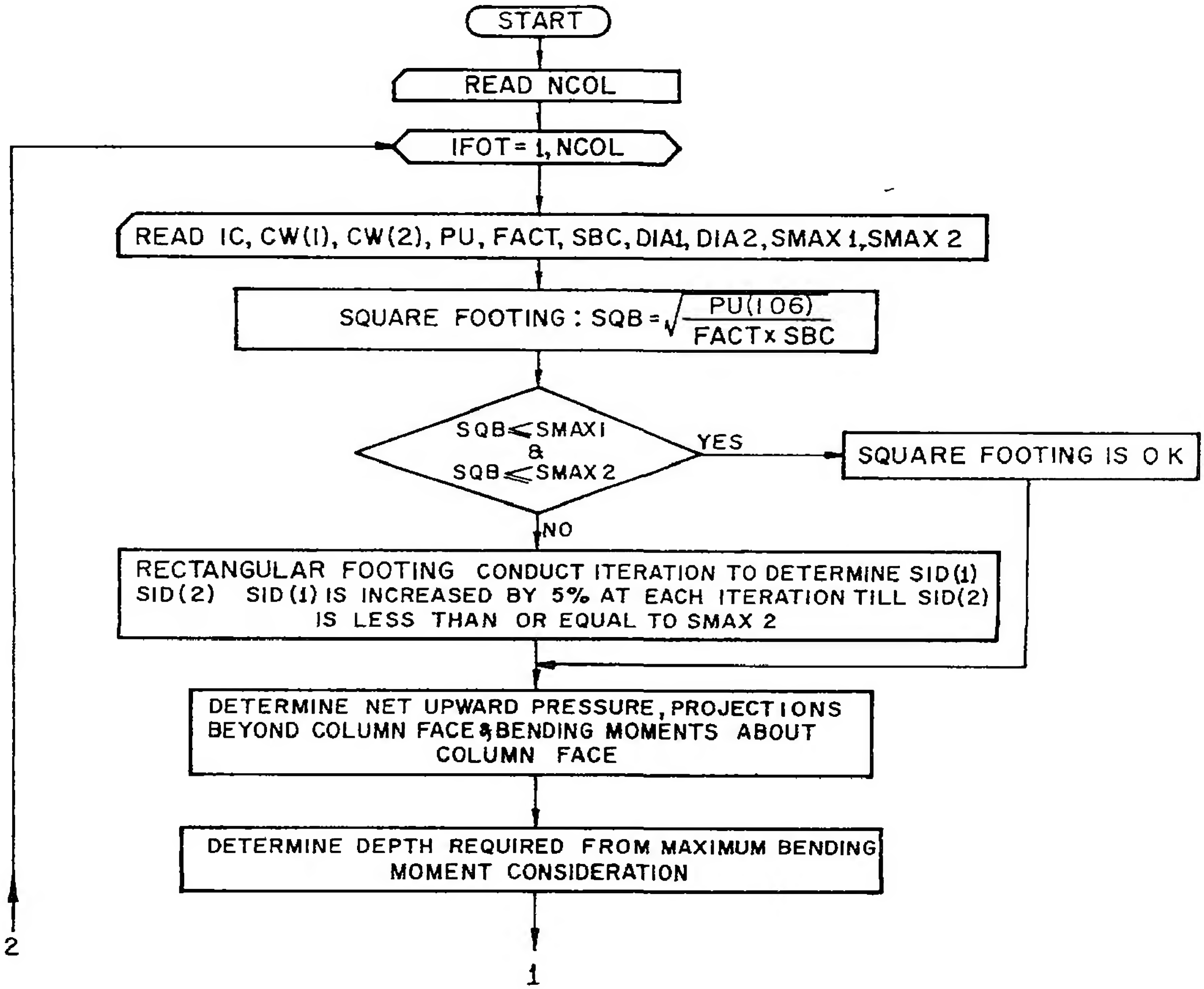


Fig.3.17 (a) General flow chart for design of isolated rectangular/square footing

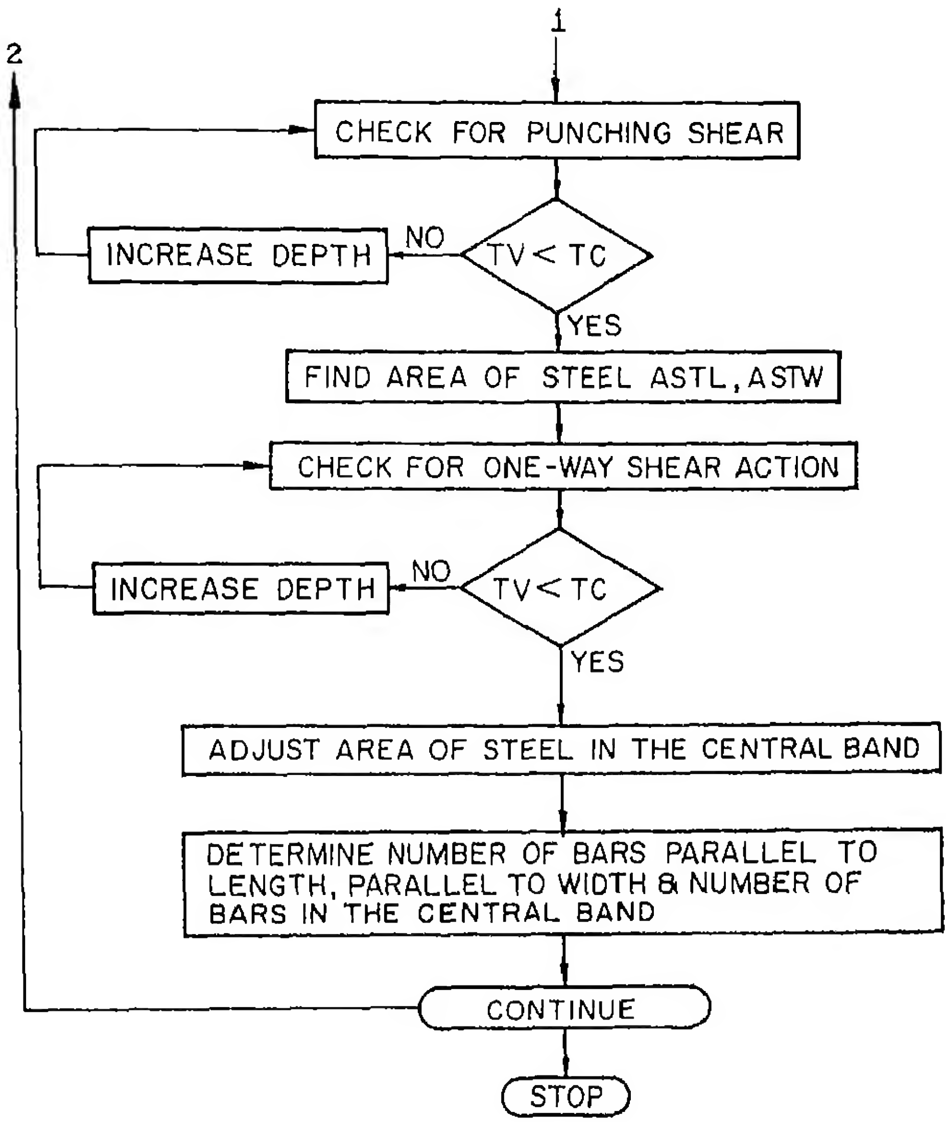


Fig 3 17(b) General flow chart for design of isolated rectangular/ square footing

CHAPTER 4 _ DISCUSSIONS AND CONCLUSIONS

4.1 Discussions . Many general purpose analysis programs are easily available now-a-days for the designer But the biggest disadvantage in using general purpose analysis programs lies in preparation of input data The preparation of input data is a very tedious job, which often causes frustration to the user For example - To analyse by stiffness method, a 12 storey - 8 bayed symmetrical building frame (number of joints =117, number of beams = 96, number of columns = 108, number of load combinations = NLC), the input data would be enormous An alarming total of (117x2) joint coordinates, (96+108) member connectivity relations, (117x3xNLC joint loads & (96x6xNLC) member fixed end actions are to be fed as input!! While preparing such data there stands no surety that no errors will creep in at any stage of the manual evaluation

Then comes the design of various components of the building frame Individiual softwares are also available for design of beams & design of columns But here again the designer has to spend lots of man-hours in feeding the input data

A large quantity of information is stored in the Indian standard codes of practice, in the form of rules/recommendations & limitations For a designer to make use of the relevant information available in different codes of practice, every time he designs may proove to be further time consuming

All the above mentioned lacunas have been reasonably obviated in the present work The joint coordinates, member connectivity relations, joint loads & the member fixed end actions are all generated by the "Preprocessor", with minimal input data An interface is established between preprocessor and analysis programs The analysis program also establishes an interface with the design program, obviating the need for fresh input The provisions of the relevant Indian standard codes of practice have been incorporated in the present work

4.2 <u>Conclusions</u> The present work was devoted to computer aided analysis and design of tall RC building frames The input/output have been classified as under -

(i) Input classification Input to the program can be classified into three parts, viz,

1) Input to generate configuration (DAT1 INP)
2) Input to generate loads & forces (DAT2 INP)
3) Input for the design of footings (FOT.INP)

The input files have been explained in detial in the preceding chapters, with the aid of tables followed by the illustrative examples

(ii) Output classification. The output files can be classified under 4 subheads -

1. Geometry data & the skeleton frame figure are present in a file named "GENE DAT" This file contains information about joint coordinates & member connectivity

2 The file "SESMIC DAT" contains the details of modal analysis of the building frame Time period, mode participation factors, horizontal seismic coefficient & lateral shears are all presented in this file.

3 The third output file "ANAL.DAT" contains the important information about the results of analysis for different load combinations The joint displacements & member forces are listed for each load combination

4. Design outputs are presented in 3 files -

"DES1.DAT" in which all the design requirements are presented "DES2.DAT" is an extension of the latter file which suggests information about reinforcement details The third file is "FOT.DAT" , which gives out information about footing size & reinforcement details

All the output files are self explanatory and are presented in the coming pages

(iii) <u>To conclude the following points have been highlighted</u> :

1. It has been demonstrated by the present work that one can develop a program for analysis & design of tall buildings which has a professional application

2. Practising engineers & architects could use packages such as the present one, and in the process without getting involved with structural details.

3 Preprocesors are labour saving devices and form the back bone of a CAD package A preprocessor specifically evolved for a certain problem will essentially be economical and useful

4 Efficient & economic designs can be achieved by using CAD packages.

5. Parametric study & optimisations can be affected with considerable ease in computer aided analysis and designs.

(iv) Scope for further work : There is an immense scope in the field of CAD, for the designer to go in for more sophistication and lesser involvement

Design of many other types of foundation systems used in tall buildings could be added to make the package more useful

Detailing of reinforcement is an art, which needs a more intensive study & careful programming Once achieved, it could wipe out the communication gap between the designer and the draftsman

A graphic support to display the bending moment and shear force diagrams can be incorporated with not much effort This would be helpful for academic purposes wherein students can have a feel of analysis, and visualise the effects of different load combinations on the frame and its components

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EXAMPLE PROBLEM FOR ILLUSTRATION , IIT Kanpur ; 1988
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

NSTO =  6 ;  NJNT =  33 ;  NBEM =  19 ;  NCOL = 27

                   1********2*********3
                   *   1    *    2    *
                   *        *         *
                   *20      *21       *22
                   *        *         *
                   *        *         *
         4*********5********6*********7
         *    3    *   4    *    5    *
         *         *        *         *
         *         *        *         *
         *23       *24      *25       *26
         *         *        *         *
         *         *        *         *
         *         *        *         *
         8*********9********10********11
         *    6    *   7    *    8    *
         *         *        *         *
         *27       *28      *29       *30
         *         *        *         *
         *         *        *         *
         *         *        *         *
         12********13*******14********15
         *    9    *   10   *    11   *
         *         *        *         *
         *31       *32      *33       *34
         *         *        *         *
         *         *        *         *
         *         *        *         *
16*******17********18*******19********20*******21
*   12   *    13   *   14   *    15   *   16   *
*        *         *        *         *        *
*35      *36       *37      *38       *39      *40
*        *         *        *         *        *
*        *         *        *         *        *
*        *         *        *         *        *
22*******23        24*******25        26*******27
*   17   *         *   18   *         *   19   *
*        *         *        *         *        *
*        *         *        *         *        *
*        *         *        *         *        *
*41      *42       *43      *44       *45      *46
*        *         *        *         *        *
*        *         *        *         *        *
*        *         *        *         *        *
*        *         *        *         *        *
*        *         *        *         *        *
28       29        30       31        32       33
```

R

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J O I N T   P R O P E R T I E S

****

Joint	X Co-or	Y Co-or	Joint	X Co-or	Y Co-or
1	8.50	0 00	2	12.70	0.00
3	17.20	0.00	4	4.00	3.00
5	8.50	3.00	6	12.70	3.00
7	17.20	3.00	8	4.00	6.20
9	8.50	6.20	10	12.70	6.20
11	17.20	6.20	12	4.00	9.40
13	8.50	9.40	14	12.70	9.40
15	17.20	9.40	16	0.00	12.60
17	4.00	12.60	18	8.50	12.60
19	12.70	12.60	20	17.20	12.60
21	21.20	12.60	22	0.00	15.80
23	4.00	15.80	24	8.50	15.80
25	12.70	15.80	26	17.20	15.80
27	21.20	15.80	28	0.00	20.30
29	4.00	20.30	30	8.50	20.30
31	12.70	20.30	32	17.20	20.30
33	21.20	20.30			

****

** ROW

M E M B E R   P R O P E R T I E S

Member	Near	Far	Length	Member	Near	Far	Length
	<< BEAMS >>				<< BEAMS >>		
1	1	2	4.20	2	2	3	4.50
3	4	5	4.50	4	5	6	4.20
5	6	7	4.50	6	8	9	4.50
7	9	10	4.20	8	10	11	4.50
9	12	13	4.50	10	13	14	4.20
11	14	15	4.50	12	16	17	4.00
13	17	18	4.50	14	18	19	4.20
15	19	20	4.50	16	20	21	4.00
17	22	23	4.00	18	24	25	4.20
19	26	27	4.00				
	<< COLUMNS >>				<< COLUMNS >>		
20	1	5	3.00	21	2	6	3 00
22	3	7	3.00	23	4	8	3.20
24	5	9	3.20	25	6	10	3.20
26	7	11	3 20	27	8	12	3.20
28	9	13	3.20	29	10	14	3.20
30	11	15	3.20	31	12	17	3.20
32	13	18	3.20	33	14	19	3.20
34	15	20	3.20	35	16	22	3.20
36	17	23	3.20	37	18	24	3.20
38	19	25	3.20	39	20	26	3.20
40	21	27	3.20	41	22	28	4.50
42	23	29	4.50	43	24	30	4.50
44	25	31	4.50	45	26	32	4.50
46	27	33	4.50				

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************************************************************        ROW

FRAME   SPACINGS
@@@@@@@@@@@@@@@@@

FORE SPACINGS =      4.00,  4.00,  4.00,  4.00,  4.00,
                     4.00,

REAR SPACINGS =      3.50,  3.50,  3.50,  3.50,  3.50,
                     3.50,
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EXAMPLE PROBLEM FOR ILLUSTRATION , IIT Kanpur ; 1988

ROW

SEISMIC ANALYSIS :: Response-Spectrum method

BETA x I x FO = 0.2000

Floor	Mode: 1	Mode: 2	Mode: 3	Lat. Shear
6	0.5164	-0.5742	0.6114	26.2042
5	0.4977	-0.4230	0.1251	37.2449
4	0.4542	-0.1220	-0 4633	30.3968
3	0.3851	0.2289	-0.4786	26.9239
2	0.2923	0.4776	0.1514	23.7260
1	0.2135	0.4427	0.3794	24.1435
AALPHA	0.0362	0.0400	0.0388	
M.P.F.	2.4951	0.6561	0.2096	
Tim. P	0.3964	0.1471	0.0846	

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<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>      ROW
EXAMPLE PROBLEM FOR ILLUSTRATION , IIT Kanpur ; 1988
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

                    A  N  A  L  Y  S  I  S
                    ~~~~~~~~~~~~~~~~~~~~~~~~

**************************************************************

     Num Floors =  6 ;  NJOINTS =  33 ;  NMEMBERS =  46 ;

     NBEMS =  19 ;  NCOLS =  27 ;

     Semi band width =  21 ;

     Density of Concrete = 0.2450E+02 ;

     Density of Wall mat = 0.1920E+02 ;

     Type of Steel =  HYSD Bars (FE415) ;

     Num of Load Combns. =   3 ;


     ---------------------------------------------------------


     Storey hts =  4.50   3.20   3.20   3.20   3.20
                   3.00

     WORKING SYSTEM OF UNITS = S I

**************************************************************
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****
LOAD COMBINATION = 1
****

DESIGN LOAD = (1.50) D.L + (1.50) L L. + (0.00) E.L./W.L.

ROW B

Jnt	Flr	Coordinates X-Cor	Coordinates Y-Cor	JOINT LOADS X-Load	JOINT LOADS Y-Load	JOINT LOADS Moment	JOINT DISPLACEMENTS X-Disp	JOINT DISPLACEMENTS Y-Disp	JOINT DISPLACEMENTS Rotatn
1	6	8.50	0.00	0.	50.	0.	0.000	0.004	0.000
2	6	12.70	0.00	0.	89.	0.	0.000	0.005	0 000
3	6	17.20	0.00	0.	64	0.	0.000	0.004	0.000
4	5	4.00	3.00	0.	84.	0.	0.000	0.003	0.000
5	5	8.50	3.00	0	158.	0.	0.000	0.004	0.000
6	5	12.70	3.00	0	171.	0.	0.000	0.005	0.000
7	5	17.20	3.00	0.	144.	0.	0.000	0.004	0.000
8	4	4.00	6.20	0.	150.	0.	0 000	0.003	0.000
9	4	8.50	6 20	0	175.	0.	0.000	0.004	0.000
10	4	12.70	6.20	0.	175.	0.	0.000	0.004	0.000
11	4	17.20	6.20	0.	150.	0.	0.000	0.003	0.000
12	3	4.00	9.40	0	150.	0.	0.000	0.002	0.000
13	3	8.50	9.40	0.	175.	0.	0.000	0.003	0.000
14	3	12.70	9.40	0.	175.	0.	0.000	0.004	0.000
15	3	17.20	9.40	0.	150.	0.	0.000	0.003	0.000
16	2	0.00	12.60	0.	104.	0.	0.000	0.001	0.000
17	2	4.00	12.60	0.	210.	0.	0.000	0.002	0.000
18	2	8.50	12.60	0	186.	0.	0.000	0.003	0.000
19	2	12.70	12.60	0.	186.	0.	0.000	0.003	0.000
20	2	17.20	12.60	0	210.	0.	0.000	0.002	0.000
21	2	21.20	12.60	0.	104.	0.	0.000	0.001	0.000
22	1	0.00	15.80	0.	226.	-113.	0.000	0.000	0.000
23	1	4.00	15.80	0.	150.	0.	0.000	0.001	0.000
24	1	8.50	15.80	0.	125.	0.	0.000	0.002	0.000
25	1	12.70	15.80	0.	125.	0.	0.000	0.002	0.000
26	1	17.20	15.80	0.	150.	0.	0 000	0.001	0.000
27	1	21.20	15.80	0.	226.	113.	0.000	0.000	0.000
28	0	0.00	20.30	0.	37.	0.	0.000	0.000	0.000
29	0	4.00	20.30	0.	37.	0.	0.000	0.000	0.000
30	0	8.50	20.30	0.	37.	0.	0.000	0.000	0.000
31	0	12.70	20.30	0.	37.	0.	0.000	0.000	0.000
32	0	17.20	20.30	0.	37.	0.	0.000	0.000	0.000

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ROW B

Jnt	Flr	Coordinates X-Cor	Y-Cor	JOINT LOADS X-Load	Y-Load	Moment	JOINT DISPLACEMENTS X-Disp	Y-Disp	Rotatn
33	0	21.20	20.30	0	37	0.	0.000	0.000	0.000

****
LOAD COMBINATION = 1
****

DESIGN LOAD = (1.50) D.L. + (1.50) L.L + (0.00) E.L./W.L.

ROW B

Num	Flr	Lenth	Width	Depth	Axial	Shear	L-Mom	R-Mom	M-Mom	B-Lod
							Moment : Sagging +ve			
				<< B E A M S >>						
1	6	4.20	0.250	0.400	32	79	-65	-60.	39.	156.
2	6	4.50	0.250	0 400	41.	89.	-71	-79.	46.	173
3	5	4.50	0.250	0.400	47.	107.	93	79.	52.	208.
4	5	4.20	0.250	0 400	5	103	-87.	-76.	45	201.
5	5	4.50	0.250	0 400	-6	115	-86.	-104	54	222.
6	4	4.50	0.250	0.400	-16.	117.	-106.	-89.	55.	228.
7	4	4.20	0 250	0 400	5.	103	84.	-81	46.	206
8	4	4.50	0.250	0 400	-2	118.	-88.	-107.	56.	228
9	3	4.50	0.250	0.400	2.	116	-103.	-91.	56.	228.
10	3	4.20	0.250	0.400	-10.	104.	-84.	-81.	46.	206.
11	3	4.50	0.250	0.400	1.	117.	-91.	-104.	55.	228.
12	2	4.00	0.250	0.400	27.	103.	-77.	-75.	46.	203.
13	2	4.50	0.250	0.400	-37.	123	-108.	-98.	60	242.
14	2	4.20	0.250	0.400	2.	110.	-91.	-88.	48.	219.
15	2	4.50	0.250	0.400	-37.	123.	-99.	-107.	61.	242.
16	2	4.00	0.250	0.400	29	104.	-72.	-80.	46.	203.
17	1	4.00	0 250	0.400	-25	152.	-136.	-109.	101.	291.
18	1	4.20	0.250	0.400	-16.	153.	-133.	-131.	113.	305.
19	1	4.00	0.250	0.400	-26.	153.	-108.	-137.	101.	291.
				<< C O L U M N S >>						
20	6	3.00	0.300	0.750	129.	-32.	65.	-31.	17.	0.
21	6	3.00	0.300	0.750	251.	-9.	11.	-18.	-4.	0.
22	6	3.00	0.300	0.750	153.	41.	-79.	45.	-17.	0.
23	5	3.20	0.300	0.750	191.	-47.	93.	-58.	18.	0.
24	5	3.20	0.300	0.750	491.	10.	-23	9.	-7.	0.
25	5	3.20	0.300	0.750	627.	2.	-7.	-2.	-4.	0.
26	5	3.20	0.300	0.750	412	36.	-59.	54.	-2.	0.
27	4	3.20	0.300	0.750	458.	-31.	48.	-51.	-2.	0.

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ROW B

Num	Flr	Lenth	Width	Depth	A.ial	Shear	L-Mom Moment	R-Mom Sagging	M-Mom +ve	B-Lod
28	4	3.20	0.300	0 750	880.	-1	4	-1	1.	0.
29	4	3.20	0.300	0 750	1014.	-1.	4.	2.	3	0.
30	4	3.20	0.300	0 750	680	33.	-52.	54	1.	0.
31	3	3.20	0.300	0.750	724.	-33.	52.	-54.	-1	0.
32	3	3.20	0.300	0 750	1270.	10	-8	25.	8.	0.
33	3	3.20	0.300	0.750	1402.	-11.	11.	-25.	-7.	0.
34	3	3.20	0 300	0.750	947.	34.	-49.	59	5.	0.
35	2	3.20	0.300	0 750	206.	-27.	77	-11.	33.	0.
36	2	3.20	0.300	0.750	1159.	31.	-21.	80.	29.	0.
37	2	3.20	0.300	0.750	1685.	-29.	17.	-75	-29.	0.
38	2	3.20	0.300	0 750	1816.	28	-14.	76.	31.	0.
39	2	3.20	0.300	0.750	1380	-32.	23.	-80.	-28.	0.
40	2	3.20	0.300	0.750	208	29.	-80.	12.	-34.	0.
41	1	4.50	0.300	0.750	584	-3	11.	0.	6.	0.
42	1	4.50	0.300	0.750	1448.	7.	-30.	0.	-15.	0.
43	1	4.50	0.300	0.750	1963.	-13.	58.	0.	29.	0.
44	1	4.50	0.300	0.750	2094	12.	-55.	0.	-28.	0.
45	1	4.50	0.300	0.750	1668	-6	28.	0.	14.	0.
46	1	4.50	0.300	0.750	586.	3.	-12.	0.	-6.	0.

ROW E

EXAMPLE PROBLEM FOR ILLUSTRATION , IIT Kanpur ; 1988

D E S I N S

DESIGN OF BEAMS & COLUMNS

****

Num Floors = 6 ; NJOINTS = 33 ;

NMEMBERS = 46 ; NBEAMS = 19 ; NCOLS = 27 ;

Desity of Concrete = 2.5000E+01 ,

Steel Yeild Strength = 0 4150E+03 (FE415)

WORKING SYSTEM OF UNITS = S I

All Dimensions in "mm"

Concrete Qnty in "m3"

Steel Qnty in "Kg"

****

R C C BEAM DESIGN DETAILS

ROW B

Mem	Fl	Lenth	Wid	Dep	Fck	AREAS OF STEEL AT Top Left	Top Cent	Top Rigt	Bot Left	Bot Cent	Bot Rigt	% OF STEEL Ltop	Cbot	Rtop	OK
1	6	4200	250	400	15	642	267	594	150	342	150	0.64	0 34	0.59	OK
2	6	4500	250	400	15	666	325	735	188	420	188	0.67	0 42	0.74	OK
3	5	4500	250	400	15	890	399	807	231	521	231	0.89	0.52	0.81	OK
4	5	4200	250	400	15	837	355	781	188	461	188	0 84	0 46	0 78	OK
5	5	4500	250	400	15	828	433	945	285	568	285	0.83	0.57	0.94	OK
6	4	4500	250	400	15	1038	445	948	379	585	379	1.04	0.58	0.95	OK
7	4	4200	250	400	15	932	365	921	272	474	272	0 93	0.47	0.92	OK
8	4	4500	250	400	15	935	445	1039	380	585	380	0.94	0.58	1 04	OK
9	3	4500	250	400	15	1096	445	1024	436	585	436	1.10	0.58	1.02	OK
10	3	4200	250	400	15	996	365	981	337	474	337	1 00	0 47	0.98	OK
11	3	4500	250	400	15	1019	445	1096	437	585	437	1.02	0.58	1.10	OK
12	2	4000	250	400	15	927	340	920	267	440	267	0.93	0.44	0.92	OK
13	2	4500	250	400	15	1066	479	1025	407	634	407	1.07	0.63	1.02	OK
14	2	4200	250	400	15	1017	392	1003	357	511	357	1.02	0.51	1.00	OK
15	2	4500	250	400	15	1028	479	1069	410	634	410	1.03	0.63	1.07	OK
16	2	4000	250	400	15	917	340	964	257	440	305	0.92	0.44	0.96	OK

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ROW B

Mem	Fl	Lenth	Wid	Dep	Fck	Top Left	Top Cent	Top Rigt	Bot Left	Bot Cent	Bot Rigt	Ltop	Cbot	Rtop	STEEL OK
17	1	4000	250	400	15	1248	589	1095	589	915	589	1.25	0 92	1 10	OK
18	1	4200	250	400	15	1199	586	1188	539	1015	539	1.20	1.01	1.19	OK
19	1	4000	250	400	15	1079	519	1250	590	915	590	1.08	0.92	1.25	OK

(Header as printed: Mem Fl Lenth Wid Dep Fck AREAS OF STEEL AT / OF STEEL OK)

ROW B

****
R C C COLUMN DESIGN DETAILS
****

Mem	Flr	Lenth	Wid	Depth	Fck	% Steel	Area Steel	Latral ties	Rem
20	6	3000	300	750	15	0.80	1800	8 300	OK
21	6	3000	300	750	15	0.80	1800	8 300	OK
22	6	3000	300	750	15	0.80	1800	8 300	OK
23	5	3200	300	750	15	0 80	1800	8 300	OK
24	5	3200	300	750	15	0 80	1800	8 300	OK
25	5	3200	300	750	15	0.80	1800	8 300	OK
26	5	3200	300	750	15	0.80	1800	8 300	OK
27	4	3200	300	750	15	0.80	1800	8 300	OK
28	4	3200	300	750	15	0.80	1800	8 300	OK
29	4	3200	300	750	15	0.80	1800	8 300	OK
30	4	3200	300	750	15	0.80	1800	8 300	OK
31	3	3200	300	750	15	0.80	1800	8 300	OK
32	3	3200	300	750	15	0.80	1800	8 300	OK
33	3	3200	300	750	15	0.80	1800	8 300	OK
34	3	3200	300	750	15	0.80	1800	8 300	OK
35	2	3200	300	750	15	0 80	1800	8 300	OK
36	2	3200	300	750	15	0 80	1800	8 300	OK

CONT CONT CONT CONT

Mem	Flr	Lenth	Wid	Depth	Fck	% Steel	Area Steel	Latral ties	Rem
37	2	3200	300	750	15	0.82	1852	8 300	OK
38	2	3200	300	750	15	1 04	2333	8 300	OK
39	2	3200	300	750	15	0.80	1800	8 300	OK
40	2	3200	300	750	15	0.80	1800	8 300	OK
41	1	4500	300	750	20	0.80	1800	8 300	OK
42	1	4500	300	750	20	0 80	1800	8 300	OK
43	1	4500	300	750	20	0.97	2174	8 300	OK
44	1	4500	300	750	20	1.20	2710	8 300	OK
45	1	4500	300	750	20	0.80	1800	8 300	OK
46	1	4500	300	750	20	0.80	1800	8 300	OK

****

R C C BEAM REINFORCEMENT DETAILS

****

ROW B

Mem	Fl	Lenth	Wid	Dep	Fck	Top Left	Top Cent	Top Rigt	Bot Left	Bot Cent	Bot Rigt	Stirrups	Conc (m3)	Stel (Kg)
1	6	4200	250	400	15	2-16 1-20	3-12	2-12 2-16	2-12	2-16	2-12	2L 8 275	0.42	30
2	6	4500	250	400	15	2-16 1-20	3-12	4-16	2-12	1-12 2-16	2-12	2L 8 275	0 45	37
3	5	4500	250	400	15	3-20	2-16	3-20	3-12	2-12 2-16	3-12	2L 8 245	0 45	44
4	5	4200	250	400	15	3-20	2-16	4-16	2-12	1-12 2-16	2-12	2L 8 255	0 42	38
5	5	4500	250	400	15	3-20	1-12 2-16	2-16 2-20	3-12	2-12 2-16	3-12	2L 8 205	0 45	48
6	4	4500	250	400	15	4-20	1-12 2-16	2-16 2-20	2-16	2-12 2-16	2-16	2L 8 215	0.45	52
7	4	4200	250	400	15	2-16 2-20	2-16	3-20	3-12	1-12 2-16	3-12	2L 8 265	0.42	42
8	4	4500	250	400	15	2-16 2-20	1-12 2-16	4-20	2-16	2-12 2-16	2-16	2L 8 205	0.45	52
9	3	4500	250	400	15	4-20	1-12 2-16	4-20	1-12 2-16	2-12 2-16	1-12 2-16	2L 8 220	0.45	55
10	3	4200	250	400	15	2-16 2-20	2-16	2-16 2-20	2-16	1-12 2-16	2-16	2L 8 270	0.42	44
11	3	4500	250	400	15	2-16 2-20	1-12 2-16	4-20	1-12 2-16	2-12 2-16	1-12 2-16	2L 8 215	0 45	55

<<<< CONT >>> <<< CONT > CONT >>> CONT >>

ROW B

Mem	Fl	Lenth	Wid	Dep	Fck	Top Left	Top Cent	Top Rigt	Bot Left	Bot Cent	Bot Rigt	Stirrups	Conc (m3)	Stel (Kg)
12	2	4000	250	400	15	3-20	2-16	3-20	3-12	1-12 2-16	3-12	2L 8 265	0.40	39
13	2	4500	250	400	15	4-20	1-12 2-16	4-20	1-12 2-16	2-16 1-20	1-12 2-16	2L 8 195	0.45	56
14	2	4200	250	400	15	2-16 2-20	2-16	2-16 2-20	2-16	2-12 2-16	2-16	2L 8 240	0.42	46
15	2	4500	250	400	15	4-20	1-12 2-16	4-20	1-12 2-16	2-16 1-20	1-12 2-16	2L 8 195	0.45	56
16	2	4000	250	400	15	3-20	2-16	2-16 2-20	3-12	1-12 2-16	3-12	2L 8 260	0.40	40
17	1	4000	250	400	15	2-16 2-25	2-12 2-16	4-20	2-12 2-16	3-20	2-12 2-16	2L 8 140	0.40	62
18	1	4200	250	400	15	4-20	2-12 2-16	4-20	2-12 2-16	2-16 2-20	2-12 2-16	2L 8 140	0.42	66
19	1	4000	250	400	15	4-20	2-12 2-16	2-16 2-25	2-12 2-16	3-20	2-12 2-16	2L 8 135	0.40	61

****
R C C COLUMN REINFORCEMENT DETAILS
****

ROW B

Mem	Flr	Lenth	Wid	Depth	Fck	Reinforcement	Latral ties	Conc (m3)	Stel (Kg)
20	6	3000	300	750	15	8-20 +	8 300	0.67	65
21	6	3000	300	750	15	8-20 +	8 300	0 67	65
22	6	3000	300	750	15	8-20 +	8 300	0.67	65
23	5	3200	300	750	15	8-20 +	8 300	0.72	69
24	5	3200	300	750	15	8-20 +	8 300	0.72	69
25	5	3200	300	750	15	8-20 +	8 300	0.72	69
26	5	3200	300	750	15	8-20 +	8 300	0.72	69
27	4	3200	300	750	15	8-20 +	8 300	0.72	69
28	4	3200	300	750	15	8-20 +	8 300	0.72	69
29	4	3200	300	750	15	8-20 +	8 300	0.72	69
30	4	3200	300	750	15	8-20 +	8 300	0.72	69
31	3	3200	300	750	15	8-20 +	8 300	0.72	69
32	3	3200	300	750	15	8-20 +	8 300	0.72	69
33	3	3200	300	750	15	8-20 +	8 300	0.72	69
34	3	3200	300	750	15	8-20 +	8 300	0 72	69
35	2	3200	300	750	15	8-20 +	8 300	0.72	69
36	2	3200	300	750	15	8-20 +	8 300	0.72	69

CONT CONT CONT CONT

ROW B

Mem	Flr	Lenth	Wid	Depth	Fcl	Reinforcement	Latral ties	Conc (m3)	Stel (Kg)
37	2	3200	300	750	15	8-20 +	8 300	0.72	69
38	2	3200	300	750	15	8-20 +	8 300	0.72	69
39	2	3200	300	750	15	8-20 +	8 300	0.72	69
40	2	3200	300	750	15	8-20 +	8 300	0.72	69
41	1	4500	300	750	20	8-20 +	8 300	1.01	98
42	1	4500	300	750	20	8-20 +	8 300	1.01	98
43	1	4500	300	750	20	8-20 +	8 300	1.01	98
44	1	4500	300	750	20	4-20 + 4-25	8 300	1.01	123
45	1	4500	300	750	20	8-20 +	8 300	1.01	98
46	1	4500	300	750	20	8-20 +	8 300	1.01	98

**ROW B

QUANTITIES OF STEEL & CONCRETE

Mem Type	Estimated - Quantities Conc (m3)	Steel(Kg)
Beams	8.17	931.62
Columns	21.06	2068.94
Total	29.23	3000 57

Estimated Qnty of Cement in Bags = 196

****

DETAILS OF INPUT FILE (FOT INP) IN FOOTING DESIGN

```
6,   18  / no  of columns, SBC of soil /
41,750.,300 ,584000 ,1 5,12 ,10 ,3000 ,3000
42,750.,300 ,1448000 ,1 5,16 ,12 ,4000 ,3200
43,750.,300 ,1963000 ,1 5,16 ,12 ,4000 ,3200.
44,750 ,300 ,2094000.,1 5,16 ,12 ,4000 ,3200
45,750 ,300 ,1668000 ,1 5,16 ,12 ,4000 ,3200
46,750 ,300 ,586000 ,1 5,12 ,10 ,3000 ,3000
/column no , longer & shorter sides of column, design axial
load,  load  factor, bar dia on longer &  shorter  sides  of
footing,maximum length & width of footing/
```

D E S I G N O F F O O T I N G S

COLUMN DETAILS			FOOTING SIZE				BAR DETAILING						
							// - Lenth			// - Width			
Num	Width	Depth	Lenth	Width	Dmax	Dmin	AST	Di	Nu	AST	Di	Nu	Cent
41	750	300	1520	1520	490	150	893	12	4	366	12	4	4
42	750	300	2390	2390	870	150	2495	16	8	1567	16	8	8
43	750	300	2780	2780	1040	150	3469	16	12	2363	16	12	12
44	750	300	2870	2870	1070	150	3685	16	13	2547	16	13	13
45	750	300	2560	2560	940	150	2887	16	10	1886	16	10	10
46	750	300	1520	1520	490	150	893	12	4	366	12	4	4

E N D   E N D   E N D

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APPENDIX B

A listing of all the active variables used in the program with their maximum dimension requirements is given here Some of the important constants used in defining the arrays are --

NS	=	Number of storeys
NJ	=	Number of joints
NM	=	Number of members (total)
MB	=	Number of beams
NLC	=	Number of load combinations
NBDOT	=	Number of beams with midspan point loads
NMOD	=	Number of modes (presently =3)
NB	=	Semi-band width

AAC(12) Average acceleration coefficient at 12 selected points on the design-spectra (data bank)

AC(3xNJ) : Combined joint load vector in direction of structure axis

AE(3xNJ) · Equivalent joint load vector (structure axis)

AJ(3xNJ) . Loads applied at joints (structure axis)

ALPHA(NMOD) : Horizontal seismic coefficient

ALT5(NS,NS) : Initially used to store mass matrix & later on to store the eigen vector

ALT6(NS,NS) : Initially used to store flexibility matrix, in 2nd stage stores dynamical matrix & in final stage stores lateral shear forces

AM(6) . Final member end actions

AMD(6) : Actions at the ends of member due to joint displacements

AML(6,NM) : Fixed end actions in members in direction of member axis

AR(3xNJ) : Support reactions (structure axis)

AXIAL(NM) : Axial load in member

A1(6), A2(6) : Working arrays used to store standard values in column design (data bank)

B(NS,IBAY(NS)) . 2-D array which stores storey number & widths of bays in a storey

B(NS,NS) · Repeated product matrix used in eigen solution

BM(6) · Bending moments in a beam at 3 locations & of 2 types (+ve & -ve)

BMC(NM) Free bending moment at midspan of member

BS(NS) : Rear spacing of frames w r.t. working frame

C(NS,NS) · Matrix for intermediate storage used in eigen solution

CBM(3) · Multiplying factor for bending moments to suit the working system of units

CEL(3) : Multiplying factor for length to suit the working system of units

CEMOD(3) : Factor used for calculating Young's modulus from characteristic strength of concrete

CLD(3) . Multiplying factor for load to suit the working system of units

CST(3) : Multiplying factor for stress to suit the working system of units

CW(2) . Column dimensions, length & breadth

CWWT(NJ) : Initially used to store cross wall thickness & later on to store total weight of cross wall on the cross beam

CX(2) : X - direction cosine for beams & columns respectively

CY(2) Y - direction cosine for beams & columns respectively

DAJ(3xNJ) Forces at joints due to dead loads

DEEP(NM) : Depth of beam or column cross section

DF(3xNJ)	.	Free joint displacements (structure axis)
DJ(3xNJ)	:	Joint displacements for all joints (structure axis)
EDAJ(NJ)	·	Vertical load at joints due to all dead weights from cross beams expect those due to walls
ELAMDA(NMOD)	:	Frequency of oscillation of the frame
ELM(2)	:	Projections of footing edge beyond the column faces
EWD(MB)	:	Dead load on beam excluding wall weights
FCK(NM)	:	Characteristic (Ch.) strength of concrete for member
FCK1(3)	:	Ch. strength of concrete for a mix 1:2.4 in 3 system of units
FCK2(3)	:	Ch. strength of concrete for a mix 1:1.5:3 in 3 system of units
FCK3(3)	:	Ch. strength of concrete for a mix 1:1:2 in 3 system of units
FDL(NLC)	:	Dead load factors
FEL(NLC)	:	Earthquake/Wind load factors
FLL(NLC)	:	Live load factors
FS(NS)	:	Fore spacing of frames w.r t working frame
FSC(6)	·	Stress in each row of reinforcement in in column cross section (c/s)
GRVTY(3)	:	Acceleration due to gravity in 3 system of units
H(NS)	:	Height of storey
IAREA(8,24)	:	Total area of steel in column c/s for a given combination & set number (data bank)
IAS1(3)	:	Max. area of top steel in a beam at 3 locations (endspans & midspan)

IAS1LC(6,NLC) Area of top steel in a beam c/s at 3 locations 2 values at each location, for a given load combination

IAS2(3) Max area of bottom steel in a beam at 3 locations

IAS2LC(6,NLC) Area of bottom steel in a beam c/s at 3 locations 2 values at each location, for a given load combination

IBAY(NS) Number of bays in a storey

IBDOT(NBDOT) . Beam numbers subjected to point loads at midspan

IBMISS(NBMISS,2) Storey number & bay number of missing beam

ID(3xNJ) Displacement indexes for joints

IHEAD(12) · An array of characters for storing title

IM(6) . Displacement indexes for a member

INI(10) An array of characters to store numbers '0'-'9'

IOFF(NS) NUmber of offset bays in each storey w r t. extreme left end

IPLOT(80,80) : A 2-D array of characters used to store the frame figure

IR(9,20) Combined area of 1st & 2nd types of steel in beams for a given combination and set number(data bank)

ISYSTM(3) · An array of characters storing the name of the working system of units

JCLINE(NS,IBAY(NS)) . 2-D array storing storey number, & code no for columns in same vertical line

JJ(NM) Near end (j^{th} end) of member

JK(NM) . Far end (k^{th} end) of member

JOK( ) : An array with code numbers used in checking input
JOK(7) CONFIG
JOK(14) LOADS

JRL(NM) : Joint restraint list

JVAR1(3) JVAR2(3) JVAR4(3) JVAR5(3)	Arrays of characters for detailing of main reinforcement in beams
JVAR3(3) JVAR6(3)	Arrays for storing provided areas of main reinforcement in beams
JVARS(4)	Array of characters for Shear reinforcement detailing in beams
JV1(3) JV2(3) JV3(3)	Dummy arrays used for working space in detailing of reinforcement in beams
KI(9)	Max number of combinations available in a particular set number in beams (data bank)
KMISS( )	An array of characters having information regarding the source of error (if any), in input feeding KMISS(7) CONFIG KMISS(14) LOADS
LBOT(9,20)	A data bank of characters used in beam design to store bar numbers, diameter of 2nd type bar in a max of 20 combinations and 9 sets
LLESS(8,24)	A data bank of characters used in column design to store dia & no of smaller dia bar in a max of 24 combinations for 8 sets
LML(NM)	Code numbers to check if a member is loaded
LMORE(8,24)	A data bank of characters used in column design to store dia & no of bigger dia bar in a max. of 24 combinations for 8 sets
LTOP(9,20)	A data bank of characters used in beam design to store dia & no of 1st type bar in a max of 20 combinations and 9 sets
NBSTO(NS)	End beam number in roof/floor
NCSTO(NS)	End column number in storey
NJSTO(NS+1)	End joint number in roof/floor
PERCEN(NLC)	Percentage steel in columns

PN(12) . Natural period at 12 selected points on the design-spectra (data bank)

PT(3) Percentage tensile steel in beam

PUFCK(12) A nondimensionalised value ($=P_u/f_{ck}bD$) at 12 selected points on the interaction curve

RMPF(NMOD) Modal participation factors for 3 modes

RL(NM) Length of member

RLAJ(3xNJ) Forces at joints due to line loads

RLIV (MB) : Intensity of live load per unit area of slab resting on beam

SF(NS) : Lateral loads due to earthquake/wind at roof/floor level

SFF(3xNJ,NB) : Overall joint stiffness matrix for free joint displacements

SID(2) : Footing dimensions (length & breadth)

SKC(NS) Initially stores combined storey stiffness & later on stores the absolute maximum values of lateral shear force

SLBTK(MB) : Average thickness of slab resting on beam

SMS(6,6) Member stiffness matrix (structure axis)

STRAIN(6) . Strain values at 6 significant points on the standard stress-strain curve

STRESS(6) : Stress values at 6 significant points on the standard stress-strain curve

TP(NMOD) : Time period

UCONC(3) : Unit weight of concrete in 3 working system of units

UMFCK(12) . A nondimensionalised value ($=M_u/f_{ck}bD^2$) at 12 selected points on the interaction curve

V(NS)		Eigen vector approximation storing current values corresponding to a particular iteration
VZERO(NS)		Eigen vector approximation storing the starting values
W(NS)		Total dead load + appropriate live load dumped on a roof/floor LOADS
W(NM)		Total load on beam . . ANALY
WDSTO(NS)	:	Total dead weight dumped on a roof/floor
WIDE(NM)		Width of beam/column cross section
WL(NM)	:	Total live load on beam
WLSTO(NS)		Total live load dumped on roof/floor
WLTK(MB)	.	Thickness of wall resting on beams
WWT(MB)	·	Total wall load on beam
X(NJ)		X - coordinate of joint
XCL(IBAY(NS))	.	X - coordinate for columns in same vertical line
Y(NJ)		Y - coordinate of joint
Y(NS)	.	Vector for temporary storage in Eigen solution < POWER >

Arayys used in the Standard Subroutines MATMUL, MATVEC, SCAVEC & VECLEN, with their maximum dimension requirement are listed below under respective headings -

1 MATMUL   A(N,N) = A(N,N) x U(N,N)
A(NS,NS)
U(NS,NS)
TEMP(NS)

2 MATVEC .   Z(N) = A(N,N) x X(N)
A(NS,NS)
X(NS)
Z(NS)

3	SCAVEC X(NS) Y(NS)	Y(N) = Constant x X(N)
4	VECLEN . X(NS)	Vector length of X(N)